Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2014

Introduction

The Water & Environmental Research Institute of the Western Pacific (WERI) is one of 54 water research institutes set up by U.S. Congressional legislation at each Land Grant University in the United States and in several territories. The Institute is now in its 41th year of operation.

WERI's mission is to seek solutions through research, teaching and outreach programs, for issues and problems associated with the location, production, distribution, and management of freshwater resources. The Institute provides its regional stakeholders Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the Federated States of Micronesia (FSM), with technical expertise in water resources related fields spanning the entire natural water cycle and spectrum of human water use, including tropical climatology, surface water hydrology, rainfall catchment systems, groundwater modeling and management, water distribution systems, soil erosion and mitigation strategies, watershed management, and various aspects of water quality. Faculty members contribute significantly to both undergraduate and graduate teaching programs at the University of Guam (UOG) and conduct vigorous research aimed at improving economic conditions and the quality of life for citizens of Guam and the regional island nations. WERI also operates a state of the technology water analytical laboratory and geographical information systems analysis and training facility.

Currently WERI has a full-time Director who is also a UOG faculty member, five (5) regular and one (1) emeritus research faculty, a water analysis laboratory manager and technician, one staff hydrologist that administrates the GIS and network system, two office staff, as well as seven (7) graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program.

WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the Institute was created specifically to administer Department of Interior funds (via the US Geological Survey) under Section 104-B of the Water Resources Research Act. WERI has responsibility for the administration of three 104-B base grants: one for Guam, one for the Commonwealth of the Northern Mariana Islands (CNMI), and one for the Federated States of Micronesia (FSM). This report summarizes the Institute's regional activities under the USGS 104-B base grant program for the period March 1, 2014 to February 28, 2015 (FY14).

During FY14, WERI faculty were involved as principal investigators and/or advisors on twenty (20) research and training projects with a combined budget of approximately $1,403,020. Funding sources for these projects, in addition to the US Geological Survey, included the National Oceanic and Atmospheric Administration, the National Weather Service, the National Science Foundation, USGS Pacific Islands Climate Science Center (PICSC), the US Military, and local agencies such as the Guam Bureau of Statistics and Plans, the Guam Environmental Protection Agency, the Guam Waterworks Authority, and direct appropriations from the Guam Legislature.

Research Program Introduction

The Water and Environmental Research Institute (WERI) Advisory Council is the body, which determines research goals and priorities for WERI in general and the USGS 104-B program in particular. The Research Advisory Council (RAC) for Guam consists of representatives from all Guam governmental agencies involved with water resources development or regulation, members of U.S. Federal agencies, military organizations on Guam that deal with water resources issues and members of the university research community. The RAC for the Commonwealth of the Northern Mariana Islands (CNMI) and the Federated States of Micronesia (FSM) consist of representatives from various government departments that deal with water resources, representatives from the local colleges, private sector engineers, environmentalists, and planners, and University of Guam research faculty. The duties of the advisory councils are to update and prioritize the research and training needs for each region. Based on regional needs, the critical research needs will be updated/revised each year.

WERI held RAC meetings in September through October 2014. Forty six (46) people attended the Guam meeting, Twenty five (25) attended the CNMI meeting, and twenty (20) attended the FSM meeting. The meetings provided a scientific forum for information exchange on new and recently completed projects. Each RAC group examined the research education and training priorities identified in past years and added or amended where appropriate.

In early November, a Request for Proposals (RFP) letter was sent out by e-mail to over two hundred (200) regional representatives in Guam, the CNMI and FSM. Recipients included all past and present RAC members; faculty members at the University of Guam, the Northern Marianas College in Saipan and the College of Micronesia in Pohnpei, and water resource professionals from several government agencies. Accompanying the RFP message were: a) a blank proposal form for submittal on the USGS Web Site, b) detailed instructions on how to fill out the form, and c) the critical water resource research, education and training needs identified for Guam, the CNMI and FSM.

A total of seventeen (17): eight (8) research proposals, five (5) environmental educational programs, and four (4) information transfer and training programs including, information transfer-education proposal titled "second conference on water sustainability issues on tropical islands, December 1-3, 2015" for co-sponsoring a conference in Hawaii with Islands Region Institutes proposals were submitted for consideration in response to the RFP - USGS 104-B. Four regional review panels, each composed of well qualified water resources professionals and RAC members were tasked with evaluating each proposal's regional relevance in accordance with the long-standing criteria listed in the RFP. Four regional review panels, each composed of well qualified water resources professionals and RAC members were tasked with evaluating each proposal's regional relevance in accordance with the long-standing criteria listed in the RFP. The appropriate proposals were e-mailed separately to each reviewer with the critical needs list for the region and a scoring form. The reviewers were advised to work independently and given two weeks to submit their scores and comments to the WERI Director. The proposal scores were then tabulated and the projects ranked in descending order of average score. Projects approved for funding were selected based on their regional ranking and availability of funds.

Prediction of Flow Duration Curves at Ungaged Stream Sites in Guam

Basic Information

Title:	Prediction of Flow Duration Curves at Ungaged Stream Sites in Guam
Project Number:	2014GU271B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Quantity
Descriptors:	None
Principal Investigators:	Leroy F. Heitz, Shahram Khosrowpanah

Publication

1. Heitz, L., Khosrowpanah, Sh., 2015, Prediction of Flow Duration Curves at Ungaged Sites in Guam , Technical Report 154, WERI, University of Guam, Mangilao, Guam, 34 pages.

PROJECT SYNOPSIS REPORT

Project Title: Prediction of Flow Duration Curves at Ungaged Stream Sites in Guam

Problem and Research Objectives

In order to properly manage a region's water resources, it is important for water managers to know the time variability of flow in the streams of that region. Not only what are the highest flows, such as what would be available from a flood frequency study, but also how the flows vary day to day, season to season, and year to year. Studies such as water supply studies, hydropower studies and those involving sediment transport depend on this kind of long term variability data in order to develop the best management practices for a region's water resources.

Guam is no different than other areas requiring water resources investigations. In order to properly carry out good water resources management, it is necessary to be able to define the variability of flow available in Guam's streams. This is normally done by direct analyses of streamflow data for the stream in question or by applying some sort of inferential techniques from a gaged to an ungaged stream or from a gaged location on a stream to an ungaged location on that same stream. Of course, the most reliable means is to use actual stream flow data measured at the point of interest. The problem in Guam, as in most locations, is that stream flow information is not available for all possible sites where information is required. What is needed is a better means of predicting the variability of flow at ungaged locations that are likely to become candidate sites for water resources investigations.

The flow duration curve provides us with a means of representing the variability of flow at a study site in a concise graphical fashion. Flow duration curves have proven to be useful in evaluation of surface water resources for water supply studies, hydropower design and planning studies, low flow studies such as in-stream flow requirements and other studies where it is desirable to define the variability of flows in streams.

The overall objective of this project was to develop average annual flow and flow durations curves for the streams in Southern Guam. These flow duration curves are essential for making studies of low flow requirements and availability of water for various surface water developments and to study the impacts of man's activities on stream flows.

The specific objectives of the research were to:

1. Develop flow duration curves for all of the previously gaged stream sites in Guam.

2. Develop techniques, based on average annual stream flow, for transferring the flow duration curve information available at the gaged locations to ungaged sites in Guam.

3. Develop estimates of average annual flow for Guam's streams.

4. Divide Guam's streams into segments based on similar flow characteristics and assign average annual flows and flow duration characteristics to the segments.

5. Divide Guam's streams into stream reaches based on stream order and assign average flows to each of the reaches.

6. Develop a set of GIS based maps showing the location and flow information for all stream reaches and segments.

7. Provide an Excel application that will compute flow duration curves for the reaches and any proposed sites and also perform analyses to determine preliminary power potential and economics for specific hydropower site locations.

Methodology

This project was divided into five phases. Each of these phases is described below.

PHASE I: Development of Flow Duration Curves for Each Gage Site

The first step was to gather all the available daily streamflow data for Guam's streams into computer spreadsheet format. The required daily flow data was downloaded from the United States Geological Survey (USGS) Pacific Islands Water Science Center web site http://hi.water.usgs.gov/. Figure 1 shows the location of the USGS stream gage sites that were available for use in the study. Figure 2 provides information on the period of record for each of gages. Those rivers that marked yellow (Figure 2) are those that used for the duration curve calculation. The period of record for each gage site was examined. Some gages were rejected because of short records. A common analysis period (1953 through 1982) was chosen for the remaining gages.

Figure 1. Location of USGS stream gage sites

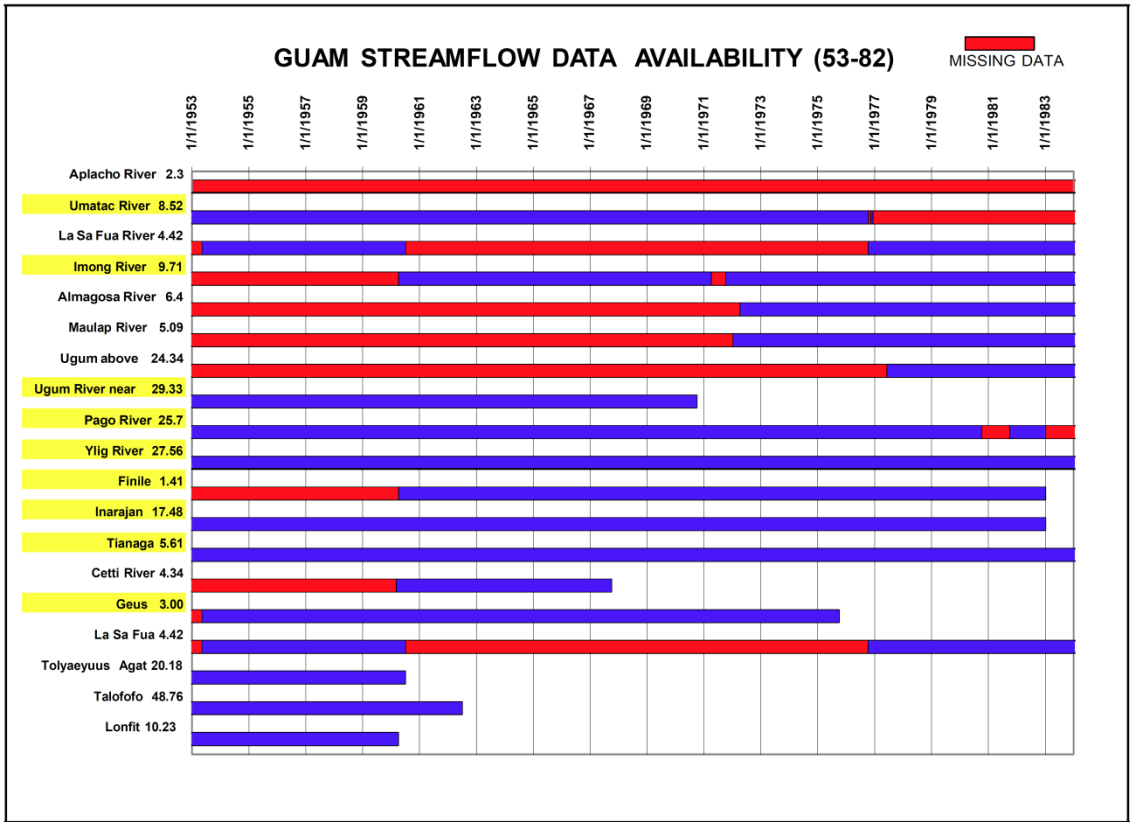


Figure 2. Gages chosen (highlighted in yellow) used in the flow duration analysis

A spreadsheet program developed specifically for use on this project assigned each of the daily flows into flow range categories specified by the user. The number of daily flow values greater than or equal to the upper limit of each category was then calculated. This value was divided by the total number of flows to find the percent of daily flows greater than or equal to the highest flow in that category. This term is called the exceedance percentage. An example of a flow duration calculation is shown in Table 1. A graph is made by plotting the exceedance percentage versus the value for the upper limit flow in each category. Figure 3 shows a typical flow duration curve for the Umatac River in Guam. Note that the duration curve is normally plotted on a semi-log axis system. The same procedure were applied to Imong, Ugum, Pago, Inarajan, Tinago, and Geus river for developing the flow duration curves for each of the river.

UMATAC FLOW DURATION TABLE 1953-1982

LOW	HIGH	IN BIN	NUMBER GREATER	% GREATER
0	0.09	0	8711	100.0000%
0.09	0.6	378	8333	95.6607%
0.6	0.8	486	7847	90.0815%
0.8	0.99	522	7325	84.0891%
0.99	1.2	493	6832	78.4296%
1.2	1.5	463	6369	73.1145%
1.5	1.9	414	5955	68.3618%
1.9	2.3	434	5521	63.3796%
2.3	2.7	428	5093	58.4663%
2.7	3.15	436	4657	53.4611%
3.15	3.7	480	4177	47.9509%
3.7	4.3	536	3641	41.7977%
4.3	5	451	3190	36.6204%
5	6	517	2673	30.6853%
6	7.5	461	2212	25.3932%
7.5	9.5	509	1703	19.5500%
9.5	12	490	1213	13.9249%
12	19	465	748	8.5868%
19	45	468	280	3.2143%
45	400	276	4	0.0459%
400	500	3	1	0.0115%
500	564	1	0	0.0000%
	TOTAL	8711		

Table 1. Flow duration table for Umatac River, Guam, (1953-1982)

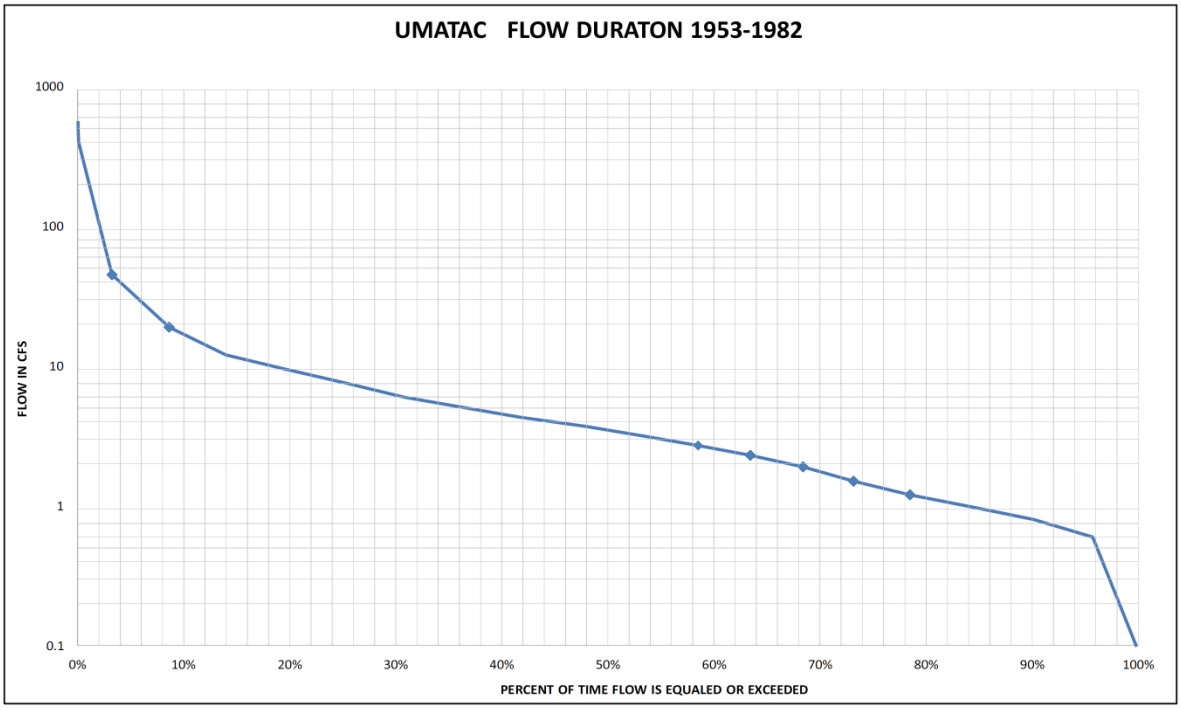


Figure 3. Flow duration curve for Umatac River, Guam (1953-1982)

PHASE II: Prediction of Duration Curves at Ungaged Sites

Phase II involved the application of a technique to predict duration curves at ungaged sites on Guam. This step is important because many sites where flow information is desired are not located at or near stream gage locations. Some may be located upstream or downstream from gaged locations and some may be located on streams where no previous stream flow records are available.

The method that was applied involved the development of parametric curves of flow versus average annual flow for chosen specific exceedance percentages. This method was originally developed by the co-investigator in a study of hydropower potential in the Pacific Northwest. The method was applied to all of the streams in Idaho to assist in determining the hydropower potential for that state.

The first step in applying the method was to take the flow values for the key exceedance percentages of Q(95%), Q(80%), Q(50%), Q(30%)), Q(10%) , and Q(0%) from each of the duration curves developed in Phase I. These particular exceedance values were chosen because these percentages provide a good distribution of exceedance flow values from low flows to high flows. Next the average annual flow was computed for each site. The values of $Q_{(\text{exceedance }\%)}$ vs Average Annual Flow were plotted for each exceedance value at each site and a best fit curve was matched to the data sets. A separate curve was developed for each key exceedance value (0% through 95%). The resulting parametric curves are shown in Figure 4.

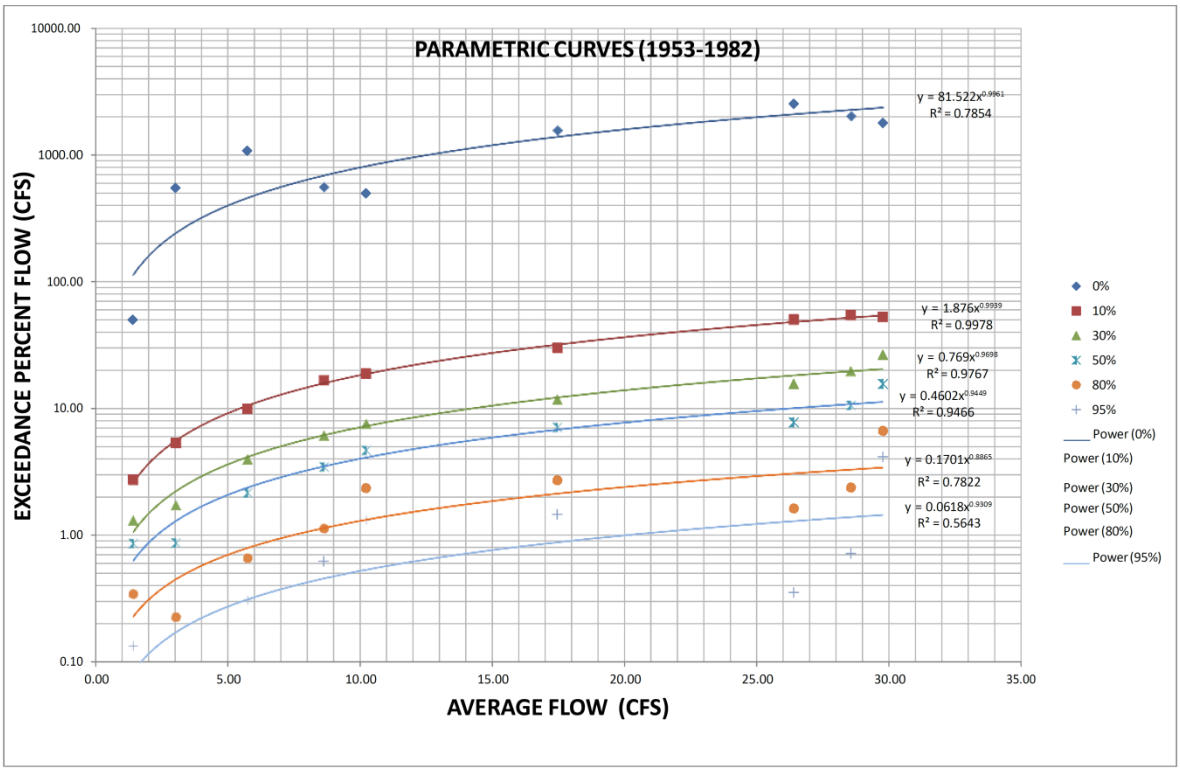


Figure 4. Parametric flow duration curves

The best fit equations are shown at the end of the curves for each exceedance percentage. Although there were limited number of data points the high R^2 values indicate a very good fit to the data by the prediction equations for most of the curves. Even the poorest fit, Q(95) equation, resulted in an explanation of 56% of the variability between average flow and the Q(95) values. These equations were used later to predict actual flows at ungaged sites or stream reaches. The regression equations took the form:

$$Q(percent) = Constant \times (Q(average\ annual))^{Power}$$

Table 2 shows the regression equations constants and R squared value for each of the regression equation developed.

PERCENT	CONSTANT	POWER	R^2
0	81.5220	0.9961	0.7854
10	1.8760	0.9939	0.9978
30	0.7690	0.9698	0.9767
50	0.4602	0.9449	0.9466
80	0.1701	0.8865	0.7822
95	0.0618	0.9309	0.5643

Table 2. Regression equation parameters and R Squared Values for each of the regression equations

PHASE III: Development of a Means to Predict Average Flow at Ungaged Points on Streams

In Phase III we developed a means to predict average flows at ungaged points on Guam's streams. The technique called for the development of grid based maps of elevations and average annual rainfall and then applying various GIS watershed functions available in the computer program ArcMap. The end products were grid and line based maps of the average annual flow in the streams. Since, not all the rainfall reaches the stream due to the losses in the hydrologic system; a correction factor called "Runoff Factor, RF" was employed. The RF factor was developed for gaged streams as shown in Table 3. A best fit curve was developed as shown so that runoff factors at ungaged sites could be predicted. These factors were multiplied by the GIS predicted rainfall input to determine the average annual flow for ungaged locations. The average flow values predicted were used as input to the parametric duration curves developed in Phase II in order to predict the duration curves at ungaged stream segments or stream reaches. The steps required to develop the average flow and duration curve values were:

1. Develop a usable grid based model of elevation (Digital Elevation Model or DEM)
2. Develop a grid based model of the accumulation of cells using the DEM.
3. Develop a grid of average annual precipitation
4. Develop a grid model of average annual precipitation input and average annual flow
5. Define streams, stream reaches and stream segments from the DEM data
6. Determine average flows in stream segments and reaches and flow variability in all stream segments.

More detail on each step is reported in (Heitz, Khosrowpanah, 2015).

STREAM GAGE	PRECIPITATION INPUT (CFS)	AVERAGE FLOW (CFS)	RUNOFF FACTOR	DRAINAGE AREA (SQ. MILES)
UMATAC	16.66	8.62	0.52	2.08
IMONG	16.50	10.22	0.62	1.91
PAGO	40.88	26.40	0.65	5.67
YLIG	46.51	28.56	0.61	6.51
FINILE	2.04	1.40	0.68	0.26
INARAJAN	33.44	17.46	0.52	4.32
TINAGO	14.76	5.73	0.39	1.91
GUESS	7.09	3.02	0.43	0.93
UGUM NR TALOFOFO	59.29	29.77	0.50	7.05

Table 3. Average runoff and precipitation input (average rainfall accumulation) for Guam's stream gage stations used in the analysis

PHASE IV: Stream Reach Delineation and Reach Average Flow Estimates

In Phase IV we divided Guam's streams into stream reaches based on stream order. This was done starting with the "Flow Accumulation" grid discussed earlier and required extensive spatial analyst processing as will be described below. The first step in the process was to specify the headwater definition for the new stream network. A minimum accumulation of cells count of 64,700 was determined to give a reasonable stream network definition for our study. What this means is that all cells in the "Flow Accumulation" grid with cell values of 64,700 or greater will be included in the stream network. The 64,700 cell accumulation value corresponds to a drainage area of 0.1 square miles or 64 acres when applied to the 2 meter by 2 meter grid used in this study. The Raster Calculator Tool of the Spatial Analyst Toolbar was applied to the "Flow Accumulation" grid to eliminate all cells with accumulations less than 64,700. This grid file was divided by itself using the Raster Calculator tool of Spatial Analysis toolbar to obtain a new Grid that contains ones in all cells where the accumulations are greater than 64,700 and "no data" in all other cells" This file will be used later to select only cells from a particular raster data set that are included in the identified streams. This new grid file was named "streams=one or no data".

Several tools from the ArcMap Spatial Analysis Toolbox were applied to the stream grid and to the previously developed average flow grid resulting in a map of average flow in each reach shown in Figure 5. Figure 6 shows a close up view of individual stream reaches on the Ugum River. The flow value is the median value of the reach average annual flow for the reach.

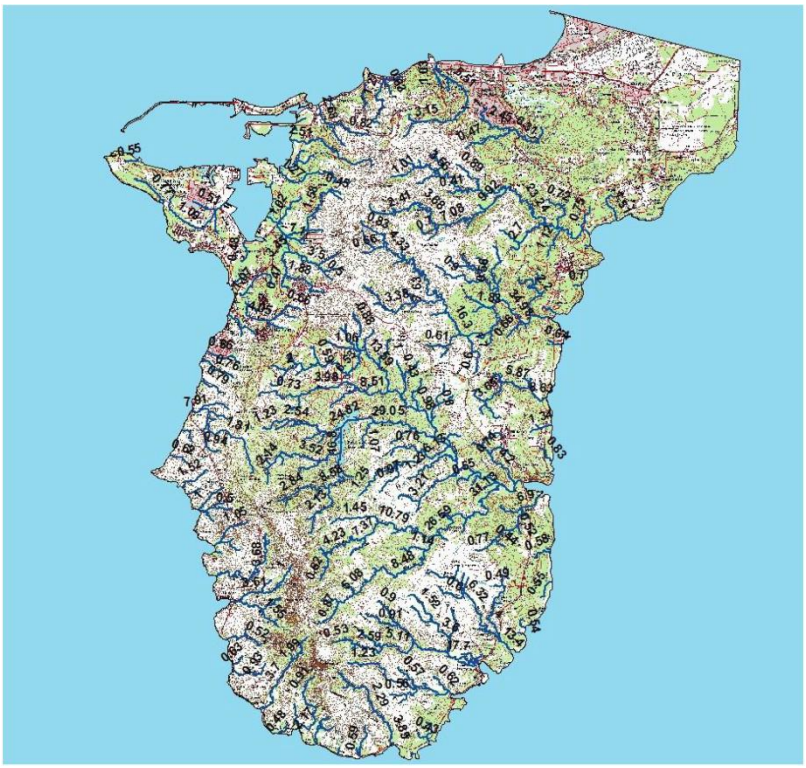


Figure 5. Guam streams and median reach flows in cfs from stream reach delineations.

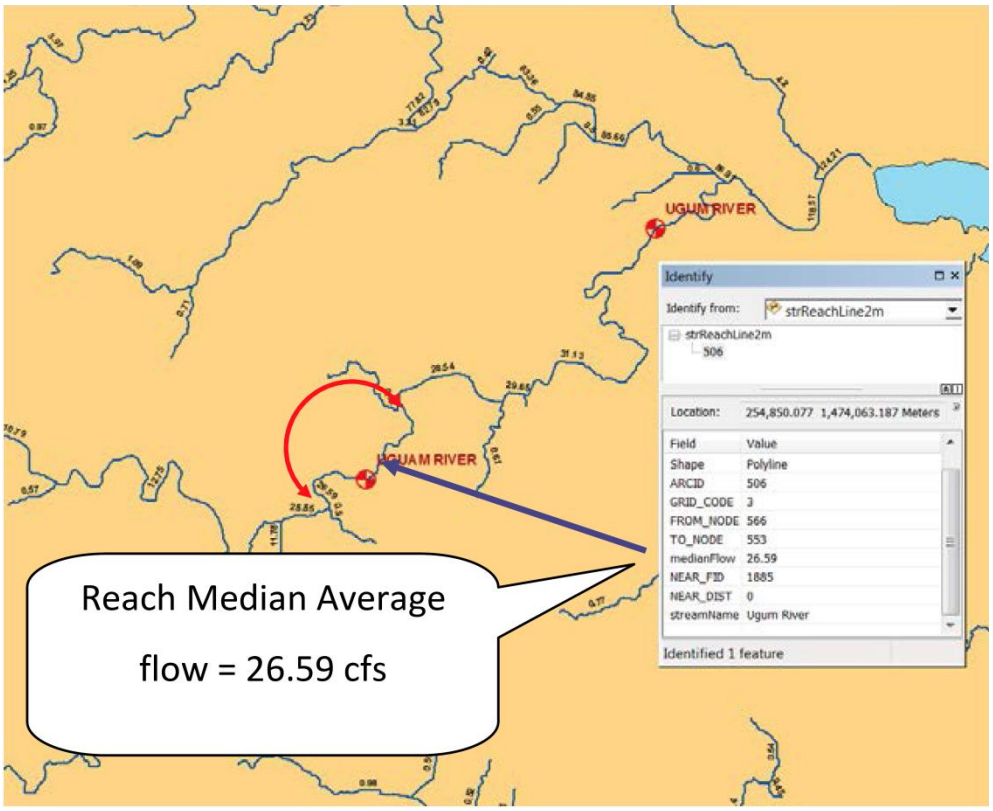
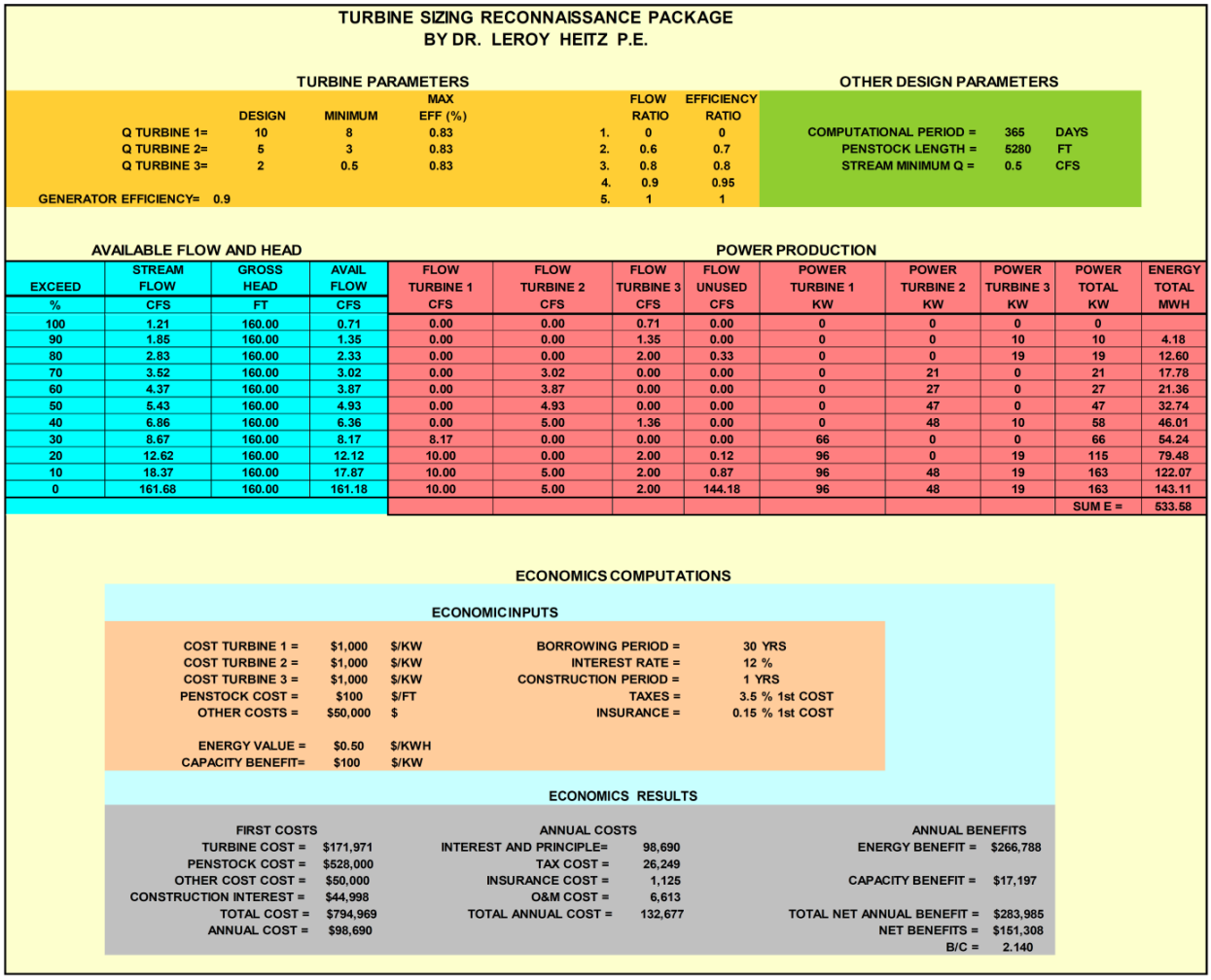


Figure 6. Individual stream reaches on the Ugum River showing estimated median average annual flow in cfs for the reach.

PHASE V: Hydro Power Production and Economic Analysis

In this Phase of the work a means of calculating the power potential and economic feasibility of potential hydropower sites in Guam was developed. A previously developed spreadsheet program was used as a basis for the new hydro power potential Excel application. The first worksheet of the application is the potential site's average annual flow which comes from the previously described GIS maps. The application computes the flow duration values using the parametric duration curves described earlier. The application also plots the flow duration curve for the selected site. The second worksheet of the application, shown in Figure 7, computes the power production and economics of the site based on the flow duration curves computed on the first worksheet and the input site head, turbine sizing information and economic considerations. This application allows the user to explore various turbine sizing and economic considerations to determine the preliminary feasibility of developing a hydropower facility at a particular site. A copy of the Excel Workbook will be made available on the WERI web site: http://www.weriguam.org/. This application can be used by those interested in carrying out their own analysis at any potential hydropower site in Guam.



TURBINE SIZING RECONNAISSANCE PACKAGE
BY DR. LEROY HEITZ P.E.

TURBINE PARAMETERS

	DESIGN	MINIMUM	MAX EFF (%)
Q TURBINE 1=	10	8	0.83
Q TURBINE 2=	5	3	0.83
Q TURBINE 3=	2	0.5	0.83

GENERATOR EFFICIENCY= 0.9

	FLOW RATIO	EFFICIENCY RATIO
1.	0	0
2.	0.6	0.7
3.	0.8	0.8
4.	0.9	0.95
5.	1	1

OTHER DESIGN PARAMETERS

COMPUTATIONAL PERIOD =	365	DAYS
PENSTOCK LENGTH =	5280	FT
STREAM MINIMUM Q =	0.5	CFS

AVAILABLE FLOW AND HEAD / POWER PRODUCTION

EXCEED	STREAM FLOW	GROSS HEAD	AVAIL FLOW	FLOW TURBINE 1	FLOW TURBINE 2	FLOW TURBINE 3	FLOW UNUSED	POWER TURBINE 1	POWER TURBINE 2	POWER TURBINE 3	POWER TOTAL	ENERGY TOTAL
%	CFS	FT	CFS	CFS	CFS	CFS	CFS	KW	KW	KW	KW	MWH
100	1.21	160.00	0.71	0.00	0.00	0.71	0.00	0	0	0	0	
90	1.85	160.00	1.35	0.00	0.00	1.35	0.00	0	0	10	10	4.18
80	2.83	160.00	2.33	0.00	0.00	2.00	0.33	0	0	19	19	12.60
70	3.52	160.00	3.02	0.00	3.02	0.00	0.00	0	21	0	21	17.78
60	4.37	160.00	3.87	0.00	3.87	0.00	0.00	0	27	0	27	21.36
50	5.43	160.00	4.93	0.00	4.93	0.00	0.00	0	47	0	47	32.74
40	6.86	160.00	6.36	0.00	5.00	1.36	0.00	0	48	10	58	46.01
30	8.67	160.00	8.17	8.17	0.00	0.00	0.00	66	0	0	66	54.24
20	12.62	160.00	12.12	10.00	0.00	2.00	0.12	96	0	19	115	79.48
10	18.37	160.00	17.87	10.00	5.00	2.00	0.87	96	48	19	163	122.07
0	161.68	160.00	161.18	10.00	5.00	2.00	144.18	96	48	19	163	143.11
											SUM E =	533.58

ECONOMICS COMPUTATIONS

ECONOMIC INPUTS

COST TURBINE 1 =	$1,000	$/KW	BORROWING PERIOD =	30	YRS
COST TURBINE 2 =	$1,000	$/KW	INTEREST RATE =	12	%
COST TURBINE 3 =	$1,000	$/KW	CONSTRUCTION PERIOD =	1	YRS
PENSTOCK COST =	$100	$/FT	TAXES =	3.5	% 1st COST
OTHER COSTS =	$50,000	$	INSURANCE =	0.15	% 1st COST
ENERGY VALUE =	$0.50	$/KWH			
CAPACITY BENEFIT=	$100	$/KW			

ECONOMICS RESULTS

FIRST COSTS		ANNUAL COSTS		ANNUAL BENEFITS	
TURBINE COST =	$171,971	INTEREST AND PRINCIPLE=	98,690	ENERGY BENEFIT =	$266,788
PENSTOCK COST =	$528,000	TAX COST =	26,249		
OTHER COST COST =	$50,000	INSURANCE COST =	1,125	CAPACITY BENEFIT =	$17,197
CONSTRUCTION INTEREST =	$44,998	O&M COST =	6,613		
TOTAL COST =	$794,969	TOTAL ANNUAL COST =	132,677	TOTAL NET ANNUAL BENEFIT =	$283,985
ANNUAL COST =	$98,690			NET BENEFITS =	$151,308
				B/C =	2.140

Figure 7. Hydropower output, turbine sizing and economic feasibility worksheet of hydropower analysis application

Principal Findings and Significance

The results of this project was the development of a means of predicting flow duration curves at ungaged sites in Guam. All of the major streams in Southern Guam were divided into stream reaches. These reaches were based on "Stream Order" of the stream segment. The reaches were identified on maps developed from the detailed Geographic Information System (GIS) map inventory of Guam available at WERI. Various statistical and analytical methods, as described in the previous methods section, were applied to the existing streamflow data along with the physical characteristics of the reaches in order to predict the streamflow variability in each stream reach. More detailed average flows and exceedance percentage flows were also provided for smaller stream segments for all the Guam streams. Average annual rainfall upstream and drainage area were also developed for each of the stream

segments. An Excel application was also developed to perform a preliminary power production and economic analysis for any new proposed site. Those wishing to explore the feasibility of hydro power at a particular site will be able to enter the average flow and available head (hydraulic drop) information into the simple spreadsheet application which will be provided as part of the study. This application will allow the user to explore various turbine sizing and economic considerations to determine the preliminary feasibility of developing a hydropower facility at a particular site.

Estimating the natural limits of the Northern Guam Lens Aquifer: A first step toward sustainable management

Basic Information

Title:	Estimating the natural limits of the Northern Guam Lens Aquifer: A first step toward sustainable management
Project Number:	2014GU272B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Mark Lander, John Jenson

Publication

1. Habana, Nathan C., John W. Jenson, Stephan B. Gingerich, and Mark A. Lander, 2015, in prep, Evaluation of the Natural Potential Capacity of the Northern Guam Lens Aquifer, Water and Environmental Research Institute of the Western Pacific, Technical Report, University of Guam, Mangilao, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Estimating the natural limits of the Northern Guam Lens Aquifer: A first step toward sustainable management

Problem and Research Objectives:
The Northern Guam Lens Aquifer (NGLA) provides 80% of Guam's drinking water. The anticipated addition of US Marine Corps activities will require additional production, while ongoing economic growth will increase demand as well. Policy-makers and water managers want to know what volumes of water can be sustainably withdrawn from various parts of the aquifer, and how increased withdrawal will affect salinity. The extent to which quantity and quality might be optimized, however, is ultimately constrained by the *natural limits* on aquifer recharge, storage, and water quality imposed by climatic and geologic conditions. This study is therefore directed at estimating the *maximum natural capacity* (superseding the obsolete concept of *sustainable yield*) of the NGLA to provide a baseline against which to evaluate future proposals for holistic sustainable management approaches.

Methodology:
This is a collaborative project between WERI and the USGS Pacific Islands Water Science Center (PIWSC) to identify ideal configurations (i.e., configurations not limited by economic, social, legal, or other non-natural factors) of well distribution and spacing, depth, and pumping rates that could in thus in principle maximize production from the aquifer for specified limits on saltwater content. The recently completed *Guam Groundwater Availability Study* (Gingerich, 2014; Gingerich and Jenson, 2010), produced a state-of-the-art groundwater model of the NGLA that is perfectly suited for the proposed study. WERI investigators, Dr. John Jenson, Dr. Mark Lander, and Dr. Nathan Habana thus obtained additional funding (from the Guam Hydrologic Survey) by which to retain Dr. Stephen Gingerich, PIWSC, who led the development of the USGS model, to provide technical support for the initialization and application of the groundwater model and to share in the interpretation and publication of results.

Principal Findings and Significance:
Drs. Jenson and Habana have developed a graphic conceptual model, which will be available to users on the WERI website. Working with Dr. Gingerich, they have also implemented the numerical model, and are testing scenarios to identity the patterns of well placement, depth, and pumping rates that maximize production for given maximum concentrations of chloride—the primary target being 150 mg/l. They are also working with Dr. Lander to develop realistic long-term wet-dry scenarios with which to estimate how aquifer potential capacity is constrained by anticipated natural changes in climate. The findings will be presented at a professional workshop in fall semester 2015, and an accompanying WERI technical report.

Develop a GIS Model for Analysis of Groundwater Quality Data in Saipan

Basic Information

Title:	Develop a GIS Model for Analysis of Groundwater Quality Data in Saipan
Project Number:	2014GU273B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Groundwater, Water Quality, Models
Descriptors:	None
Principal Investigators:	Yuming Wen, Brian Bearden

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Develop a GIS Model for Analysis of Groundwater Quality Data in Saipan

Problem and Research Objectives

Providing safe and adequate drinking water is a daily challenge for utility agencies in the tropical islands of the Western Pacific. These islands are facing with adverse environmental conditions such as drought, typhoon, sea level rise, unique geological condition, and increase of population. This is especially true for the island of Saipan, capital of the Commonwealth of the Northern Mariana Islands (CNMI). In 2006, the EPA acknowledged that the lack of safe drinking water was among the top environmental challenges facing the CNMI, particularly Saipan (Erediano, 2006). To improve this deficiency, it is important to monitor water quality of the aquifers, locate drinking wells with quality deficiency, and monitor trends of water quality from drinking water wells. Model the fate and transport of contaminants such as nitrate, phosphate and chlorides, organic compounds, and thallium containing compounds through CNMI's aquifers was identified as one of the critical research needs for CNMI at the CNMI Research Advisory Meetings in the past few years. To monitor the contaminant levels from drinking water wells, the state of the art technology geographic information systems (GIS) was applied to conduct spatio-temporal analysis of groundwater quality data from the drinking wells in Saipan. The overall objectives of this project were, to 1) processing groundwater quality data in a way so that they could be further processed and linked to a GIS format, 2) analyzing groundwater quality data geographically and over time, 3) identifying drinking water wells that had deficient water quality or that might develop deficient water quality, and 4) establishing a GIS-based model for visualization of groundwater quality data, and analysis of groundwater quality geographically and over time.

Methodology

There are 165 wells in Saipan (Figure 1), and 45 of the wells were sampled for the purpose of water quality assessment. The sampled wells are clustered in two locations, i.e., some are located in the central southeast, and others are located in the middle of the south near the Saipan International Airport. The red dots in the inset maps indicate the locations for the sampled wells. GIS was main technology used to process and analyze data related to groundwater quality from drinking water wells in Saipan. The primary procedures for the project included 1) obtaining groundwater quality data in Saipan; 2) Geo-coding the data to a GIS format for further processing and analysis; and 3) establishing a GIS-based model for visualization and analysis of the groundwater quality data spatially and over time. Data applied in this project included a shape file for well locations, and a Microsoft Excel spreadsheet file for water quality data of 2010 and 2011 (Table1). The data included conductivity, turbidity, nitrate, hardness, total coliform, Escherichia coli (E.coli), total dissolvent solids (TDS), pH, salinity and ammonia. The water quality data was geo-coded to a shape file and linked to a shape file for locations of wells.

Principal Findings and Significance

The main purpose of the project aimed to create a GIS based model for processing, visualization and analysis of the groundwater quality data in Saipan. In order to address the main purpose, a Visual Basic for Applications (VBA) based GIS model has been created to display the ground

water quality data spatially and temporally. The model can be applied to visualize and analyze water quality data, and identify deficient wells with contaminants more straightforward. The model can be employed to represent any contaminant in any well temporally, and any contaminant for all wells in any specific time.

Enclosed are some graphics used to indicate water quality data in space and time. Figures 2 and 3 display the salinity levels and pH values collected in June 2011 for all wells respectively.
The GIS-based model will be an efficient way for processing, visualization and analysis of the water quality data in Saipan and other islands in the western Pacific. The information and results from this project can be utilized to evaluate whether there is relationship between land cover change and/or human induced activities and water quality in Saipan, impacts of climate change on water quality, and how water quality affects human health and ecosystems in Saipan.

Note: **blue** stands for real values from samples, and white for no samples or no data or non-detectable value (ND).

well_ID	coll_date	coll_time	turb (NTU)	temp (C)	spCond (uS/cm)	TDS (ppt)	Sal (ppt)	pH	TC (total coliform)	EC (E Coli)	hardness (	nitrate (mg/l)	ammonia (mg/l)
KG-2	6/27/2011	8:58 AM	2.19	30.78	7643	4.968	4.18	6.97	0	0	1110	2.75	
KG-3	6/27/2011	9:11 AM	0.80	28.05	8590	5.575	4.75	7.10	0	0	1280	2.08	
KG-131	6/27/2011	9:16 AM	0.29	27.89	6879	4.471	3.75	7.09	0	0	1060	3.11	
KG-19	6/27/2011	9:23 AM	0.24	28.06	2000	1.298	1.01	6.91	31	0	550	9.31	
KG-6	6/27/2011	9:32 AM	0.18	28.20	4651	3.024	2.47	6.99	0	0	880	1.37	
KG-8	6/27/2011	9:42 AM	0.83	28.19	282	1.938	1.54	7.11	0	0	590	2.62	
KG-7	6/27/2011	9:48 AM	0.21	28.58	1891	1.228	0.95	7.24	0	0	430	5.74	
KG-15	6/27/2011	9:53 AM	0.13	28.34	1740	1.131	0.87	7.20	0	0	360	4.60	
KG-9	6/27/2011	9:58 AM	0.11	28.41	2099	1.365	1.06	7.21	0	0	460	5.49	
KG-16	6/27/2011	10:10 AM	0.17	28.69	1963	1.276	0.99	7.25	0	0	430	9.05	
KG-14	6/27/2011	10:16 AM	0.16	28.30	1497	0.973	0.75	6.98	0	0	390	9.06	
KG-13	6/27/2011	10:22 AM	0.83	28.07	1517	0.986	0.76	7.10	1	0	410	7.21	
KG-12	6/27/2011	10:26 AM	0.15	28.05	5248	3.413	2.81	7.15	0	0	800	7.15	
KG-11	6/27/2011	10:31 AM	0.26	28.15	7526	4.893	4.13	7.10	0	0	1100	5.74	
KG-10	6/27/2011	10:38 AM	0.35	28.34	1488	0.968	0.74	7.06	0	0	450	4.50	
DD-8	6/28/2011	8:53 AM	0.59	28.40	3395	2.209	1.77	6.97	0	0	630	6.56	
IF-105	6/28/2011	8:59 AM	0.62	28.55	4796	3.118	2.55	6.99	0	0	780	8.98	
IF-4	6/28/2011	9:03 AM											
IF-3	6/28/2011	9:05 AM	0.88	28.65	5344	3.474	2.86	7.06	1	0	790	6.68	
IF-217	6/28/2011	9:09 AM	0.96	29.26	4513	2.935	2.39	7.20	0	0	700	6.73	
IF-211	6/28/2011	9:15 AM	0.60	29.23	2881	1.872	1.48	7.01	0	0	540	7.61	
IF-1	6/28/2011	9:20 AM	0.64	28.84	4249	2.762	2.24	7.14	0	0	700	7.49	
IF-220	6/28/2011	9:25 AM	0.72	29.70	4045	2.629	2.12	6.96	0	0	640	7.11	
IF-6	6/28/2011	9:30 AM	0.76	28.54	4935	3.208	2.63	7.09	1	0	740	8.64	
IF-5	6/28/2011	9:34 AM	0.40	28.97	2915	1.895	1.50	7.06	5	0	560	10.70	
IF-205	6/28/2011	9:38 AM	1.55	29.29	7367	4.789	4.03	6.59	0	0	1010	7.55	
IF-204	6/28/2011	10:05 AM	0.72	29.11	15240	9.913	8.83	6.97	0	0	1990	6.71	
IF-203	6/28/2011	10:10 AM											
IF-202	6/28/2011	10:13 AM	1.56	29.02	5246	3.406	2.80	7.11	0	0	570	9.02	
IF-201	6/28/2011	10:17 AM	0.66	28.73	10180	6.618	5.71	7.05	0	0	1520	7.23	
IF-21	6/28/2011	10:26 AM	0.78	28.55	4281	2.782	2.26	7.06	0	0	620	6.80	
IF-20	6/28/2011												
IF-19	6/28/2011	10:33 AM	1.22	29.38	5357	3.485	2.87	7.20	12	0	780	7.17	
IF-16	6/28/2011	10:41 AM	0.66	29.01	5300	3.444	2.83	7.19	0	0	770	6.62	
IF-22	6/28/2011	10:53 AM											
IF-101	6/28/2011	10:55 AM	1.02	28.61	6446	4.189	3.49	7.11	0	0	950	4.38	
IF-23	6/28/2011	11:00 AM	0.71	28.66	1658	1.075	0.83	7.26	102	0	420	3.80	
IF-24	6/28/2011	11:05 AM	0.68	28.65	1031	0.670	0.51	7.34	0	0	340	4.11	
IF-108	6/28/2011	11:15 AM	0.74	28.72	3985	2.591	2.10	7.21	0	0	640	5.07	
IF-102	6/28/2011	11:19 AM	1.16	28.33	5459	3.549	2.93	7.09	0	0	770	6.10	
IF-12	6/28/2011	11:25 AM	0.79	28.35	4475	2.908	2.37	7.08	9	0	710	7.23	
IF-11	6/28/2011	11:30 AM	1.30	28.49	3240	2.105	1.68	7.25	0	0	570	5.34	
IF-106	6/28/2011	11:35 AM	1.16	28.26	8102	5.267	4.47	7.00	0	0	1120	9.42	
IF-7	6/28/2011	11:38 AM	1.25	28.53	6184	4.020	3.35	7.33	1	0	870	9.53	
IF-8	6/28/2011	11:44 AM	0.60	28.25	2370	1.537	1.21	7.14	0	0	480	3.48	

Jun 2011 | Mar 2011 | Nov 2010 | Sep 2010

Table 1. Water quality data collected from selected wells, June 2011

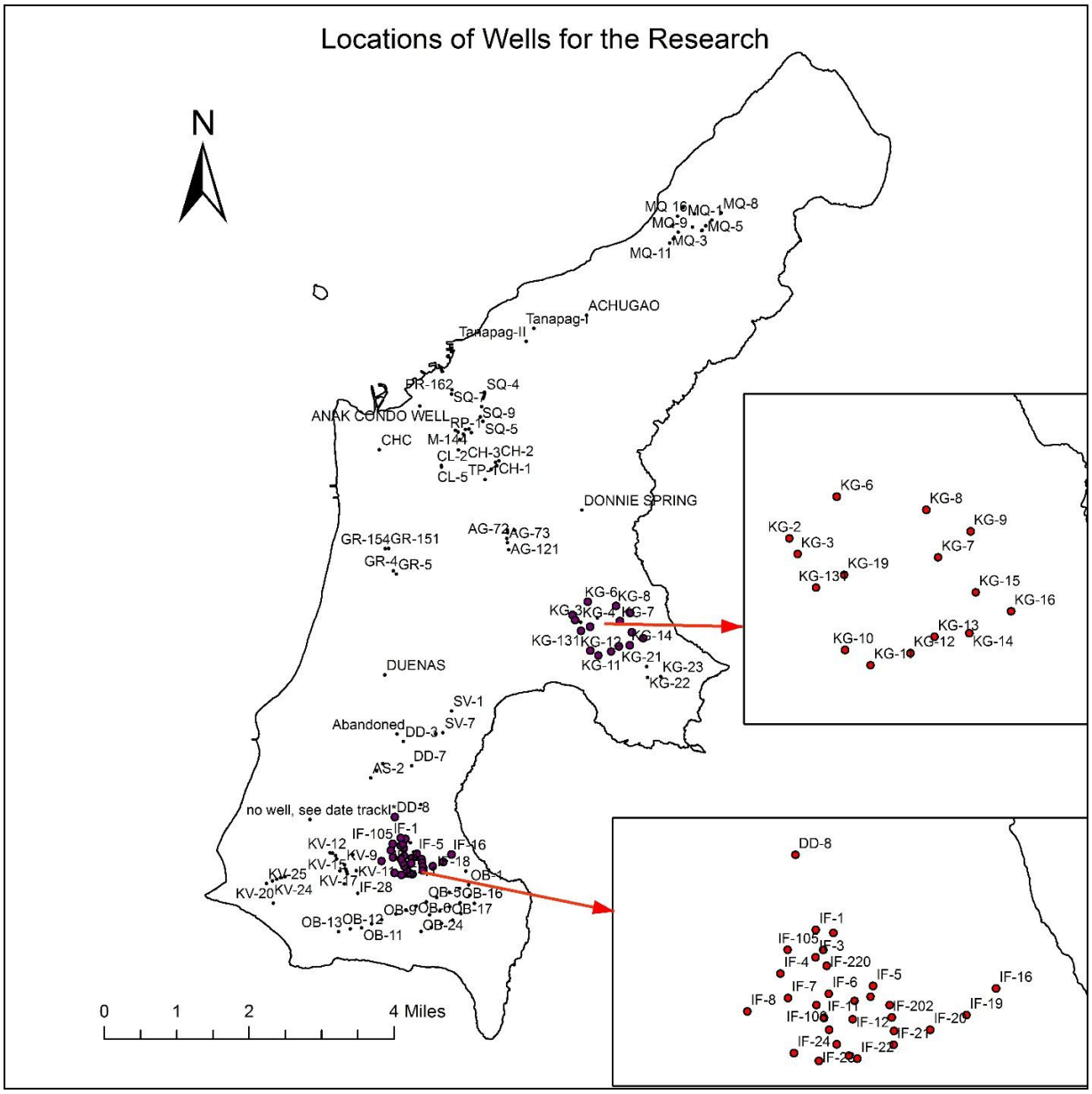


Figure 1. Water quality data collected in June 2011 linked to a shape file

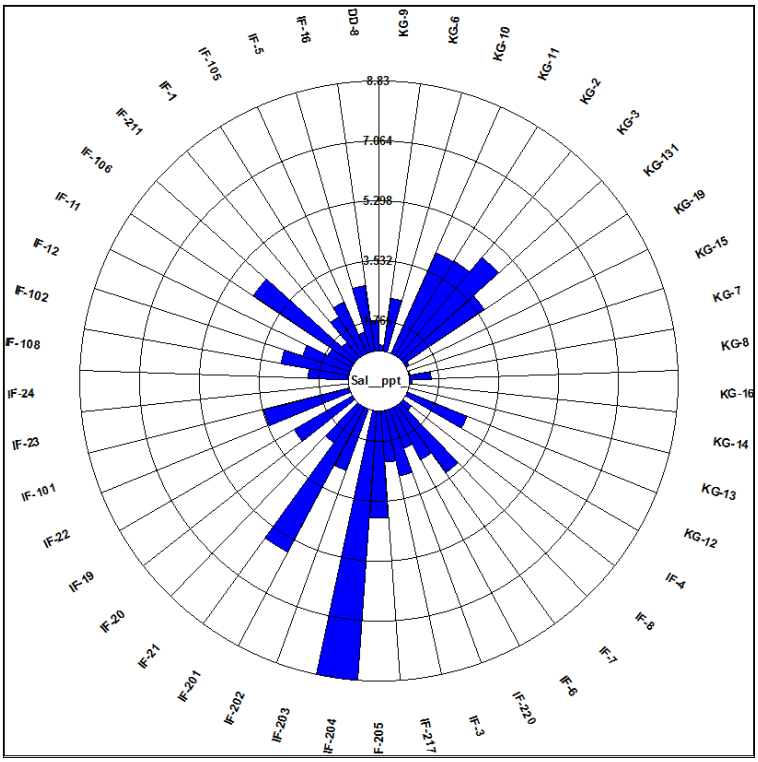


Figure 2. Salinity levels collected in June, 2011

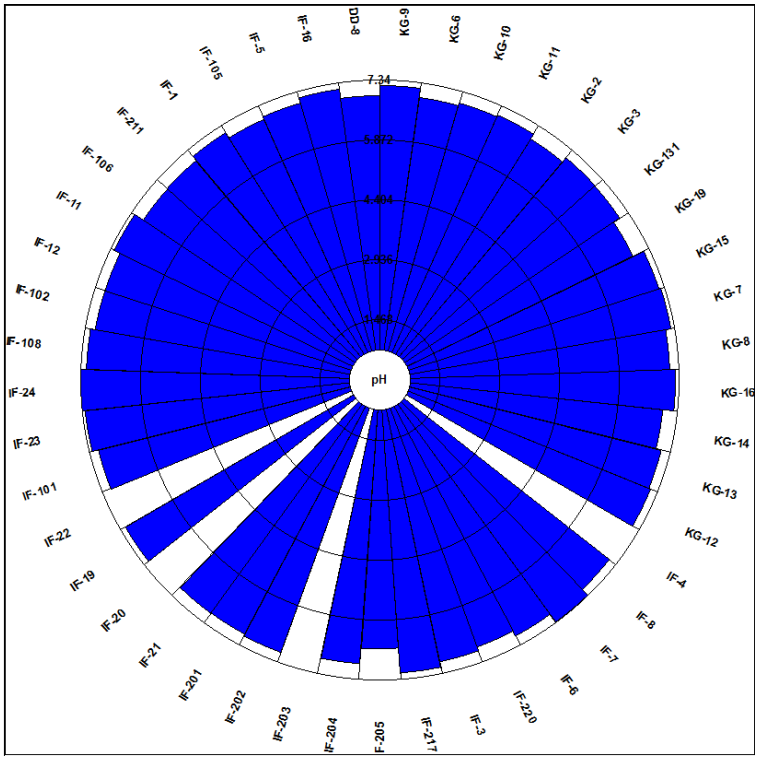


Figure 3. pH values collected in June, 2011

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Measurement of Groundwater Salinity for Selected Production Wells, Island of Saipan, CNMI

Basic Information

Title:	Measurement of Groundwater Salinity for Selected Production Wells, Island of Saipan, CNMI
Project Number:	2014GU274B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Groundwater, Water Quality, Water Supply
Descriptors:	None
Principal Investigators:	Elena Alexandrova, Heidi Yelin

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Measurement of Groundwater Salinity for Selected Production Wells, Island of Saipan, CNMI, 2014-2015

Problem and Research Objectives:

Elevated salinity is a common concern for users of the municipal water system on the Island of Saipan. A quantitative measure of groundwater salinity is concentration of chlorides, which are found as natural salts of sodium, potassium, and calcium. The salty taste of water depends on concentrations of sodium and calcium chloride and is detectable to the palate in concentrations of 200-300 mg/l (WHO, 1996). Under National Secondary Drinking Water Regulations, chloride-ion is a secondary contaminant with a limit of 250 mg/l. The USEPA does not enforce "secondary maximum contaminant level" (SMCL). Secondary limits are established as a guideline to assist public water systems in managing their drinking water's aesthetic considerations such as taste, color and odor. Chloride ions are non- toxic for humans, however long term consumption of water containing 2.5 mg/l chloride combined with sodium is reported to be related to hypertension development (WHO, 1996).

Infrastructure damage from high chloride water is another problem and it includes plumbing system corrosion, leading to increased levels of metals in drinking water. Soil deterioration through agricultural irrigation is a concern, however CUC treated water is not intended for farming use. While the USEPA recommended concentration for chlorides is 250 mg/l (EPA, 1986) and desired chloride-ion concentration in groundwater is less than 2 percent of its level in sea water (about 380 mg/L), (Hoffman, Carruth, 1998), measurements from some production wells in Saipan have exceeded 3,000 mg/l. Monitoring for chlorides is performed by CUC on a semi-annual basis for all production wells.

Groundwater resources originate entirely from rainfall. The fresh water lens floats on denser underlying water derived from the ocean. Precipitation percolates through the unsaturated limestone host unit to recharge the upper levels of the fresh water aquifer.

The aquifer supplies potable water from several well fields (Figure 1). Some of these fields have historically shown high salinity (chloride ion) because of high well density, high pumping rates that exceed the recharge rates of the reservoir, very deep pump placement, and proximity to the transition zone between the fresh and saltwater layers. This water quality problem has been addressed by past researchers (Van der Brug, 1985, Hoffman, 1998, Carruth, 2003); however, more recent water quality data has not been compiled and assessed.

It is important to note changes in island population (a significant decrease) and an increase in utility costs have also resulted in lower water consumption from metered

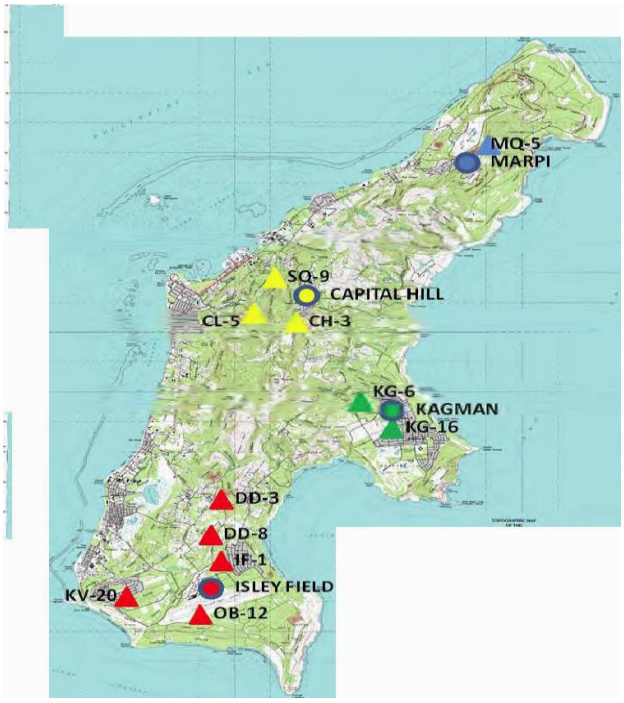

Figure 1. Study Area, Island of Saipan

customers. This decrease occurred over the last five years and it matches the period this report terms "historical data" (2009-2013).

This project's aim was to update and improve the understanding of salinity in Saipan's groundwater through an evaluation of historical and current water quality conditions. The predicted correlation of water salinity with changes in precipitation, and pumping rates through time was also assessed.

Methodology

This project was conducted by the staff of the CUC Water Quality Laboratory. Water Division personnel also assisted occasionally in sample collection and transport.

Historical (2009-2013) rainfall data was obtained from the recording gages at Isley Field and at the Emergency Management Office facility on Capital Hill. Two additional gages were installed and monitored for this project, one in Marpi (MQ-5 well site) and one on the east side of the island in Kagman (KG-4 well site). Rain gage precipitation data (in digital form) was downloaded in the field, concurrently with well sampling events for chloride content analysis.

Eleven active production wells were selected throughout the island for use in this study. Their location was chosen to produce higher geographic coverage and to represent most well fields. The CUC Water Quality Laboratory records provided historical (2009-2013) salinity data for these study wells. Between March, 2014 and February, 2015 groundwater samples were collected and analyzed every two weeks. Field samples were collected at the well head sampling tap where they were placed in plastic "Nalgene" bottles. At this time temperature, conductivity, and pH were measured. Once samples were delivered at the Laboratory, analysis for chlorides using Argentometric standard method (SM 4500-Cl-B) was conducted.

Analytical results were plotted on line charts. This information was compared with precipitation information collected throughout the study period (2014-2015). This work resulted in production of a current record of salinity as chlorides that were then correlated with precipitation and pumping rate information. For correlation calculations the amount of precipitation assigned to each chloride analytical value corresponds to the cumulative amount measured during the preceding two week period. Calculation of pumping rates, also known as well discharge (in Gal/min) were made using bi-weekly well meter readings. This well production data was collected with the assistance of CUC's Water Operations Division.

Observations

Historical and current rainfall trends (Table 1, Figure 2, and 3). The four rain gage stations on Saipan show different totals, the highest precipitation occurs at the Capital Hill gage (91 inches, elevation 600 feet) and the lowest precipitation is in Kagman (78 inches, elevation 220 feet). A distinct two-season annual period is observed in both the historical and study years (2014-2015) periods. Annual distribution trends are similar when comparing current year precipitation to the previous five year (historical amounts).

Historical and current year chloride concentration bar charts for dry and wet seasons (Figures 4 and 5). These figures show there is a minor variation in chloride levels between the first and second half of the calendar years. The change can be both increasing or decreasing, is generally small in magnitude. No conclusion can be drawn from these charts.

Mean chloride concentration for wells in order of proximity to Shore (Figure 6). No continuous variation or trend is observed between this study's wells, with the exception of CH-3 in Capital Hill. The Capital Hill well field produces high quality water from a perched aquifer at elevation, and as such is not physically connected to other well fields described in this study.

Pumping rates/discharge analysis (Figure 7). A noticeable decrease in well discharge rates is seen when comparing 1998 and 2014-2015 levels (64% of wells are producing less water in 2014-2015). As pumping rates have been reduced through time in some wells, the quality of water pumped improved. At the same time the opposite has been observed (water quality decreased with lower pumping rates). This may indicate pumping rates need to be lowered even more, to allow for aquifer recovery. Discharge rates measured during this study range from 30 to 91 Gal/min.

Table 1: Rainfall data collected for this study at four gages, with mean value, 2014-2015

Month	Isley Field	Capitol Hill	Kagman	Marpi	2014-2015 Mean
Mar-14	3.16	3.02	3.67	*2.82*	3.17
Apr-14	4.41	5.36	1.66	4.01	3.86
May-14	4.87	3.29	3.86	*4.54*	4.14
Jun-14	4.12	5.48	5.93	3.61	4.79
Jul-14	10.64	10.26	9.58	7.96	9.61
Aug-14	9.33	7.10	6.91	5.71	7.26
Sep-14	19.31	21.30	20.92	24.10	21.41
Oct-14	11.15	11.85	9.49	14.20	11.67
Nov-14	14.87	11.47	8.81	11.45	11.65
Dec-14	1.81	2.69	2.01	2.98	2.37
Jan-15	4.66	8.61	5.06	6.60	6.23
Feb-15	0.13	0.29	0.28	0.24	0.24
Total	**88.46**	**90.72**	**78.18**	**88.22**	**86.40**

Finally, analytical work for this study was conducted on samples collected from active wells. Due to their disturbed state and continued influence on the aquifer these wells are not the ideal source for studying the effects of rainfall on subsurface conditions. Future studies may benefit from measurements collected at static hydrologic conditions, such as those found in monitoring wells.

2014-2015 Chloride and Precipitation overall map (Figure 8). Many well fields operated by CUC present elevated chloride levels. These well fields also contain the highest density of operating wells and they are the higher volume producers. The best water quality is produced from the elevated water table in Capital Hill area (well CH-3).

The combination of data collected and logged by the CUC Water Quality Laboratory together with new field measurements served to add to the current understanding of the island's groundwater quality. This project addresses needs listed in the WERI/CNMI Advisory Council priority document reviewed at October 17, 2013 meeting in Saipan.

It is the hope of the authors of this research that this data will be shared with the utilities Water and Engineering and Operations departments, as well as DEQ's Safe Water Drinking Division. The study's results may also be presented to the local community at events like the MIWOA's (Marianas Island Water Operator Association) meetings.

Grant funding for this project was used for the purchase of analytical supplies and equipment. CUC made in kind contributions through a vehicle for staff transportation to the study wells, and with labor hours that allowed for sample collection and analysis.

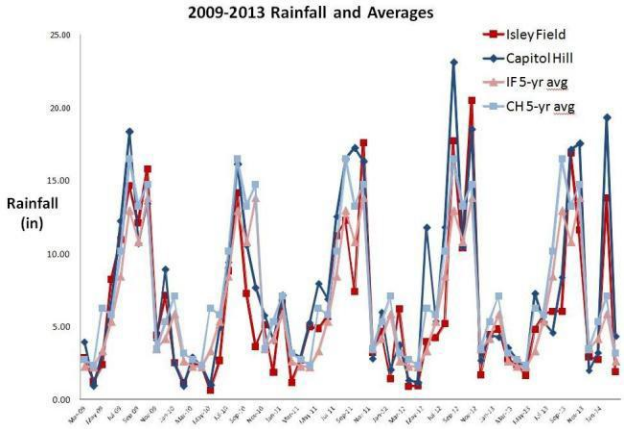

Figure 2. Rainfall data 2009-2013

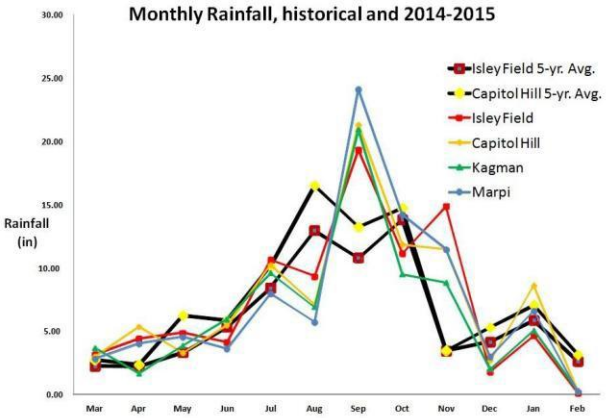

Figure 3. Rainfall data 2014-2015

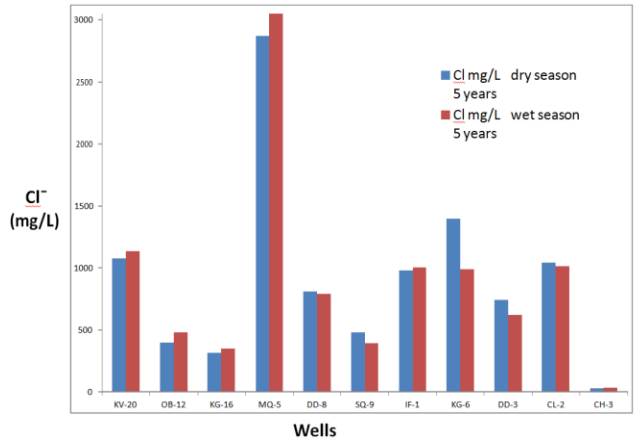

Figure 4. 2009-2013 Chloride concentration dry & wet season

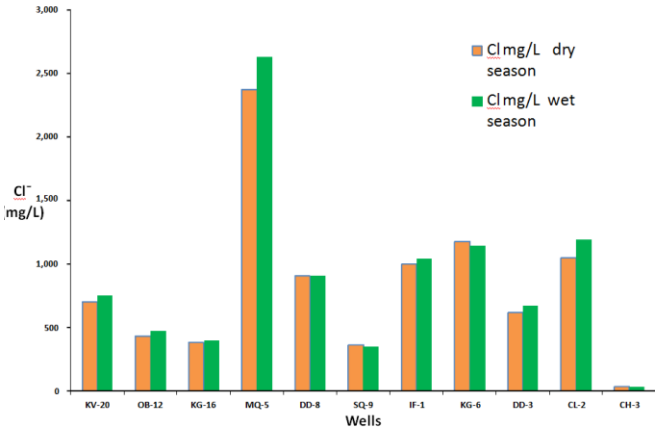

Figure 5. 2014-2015 Chloride concentration dry and wet season

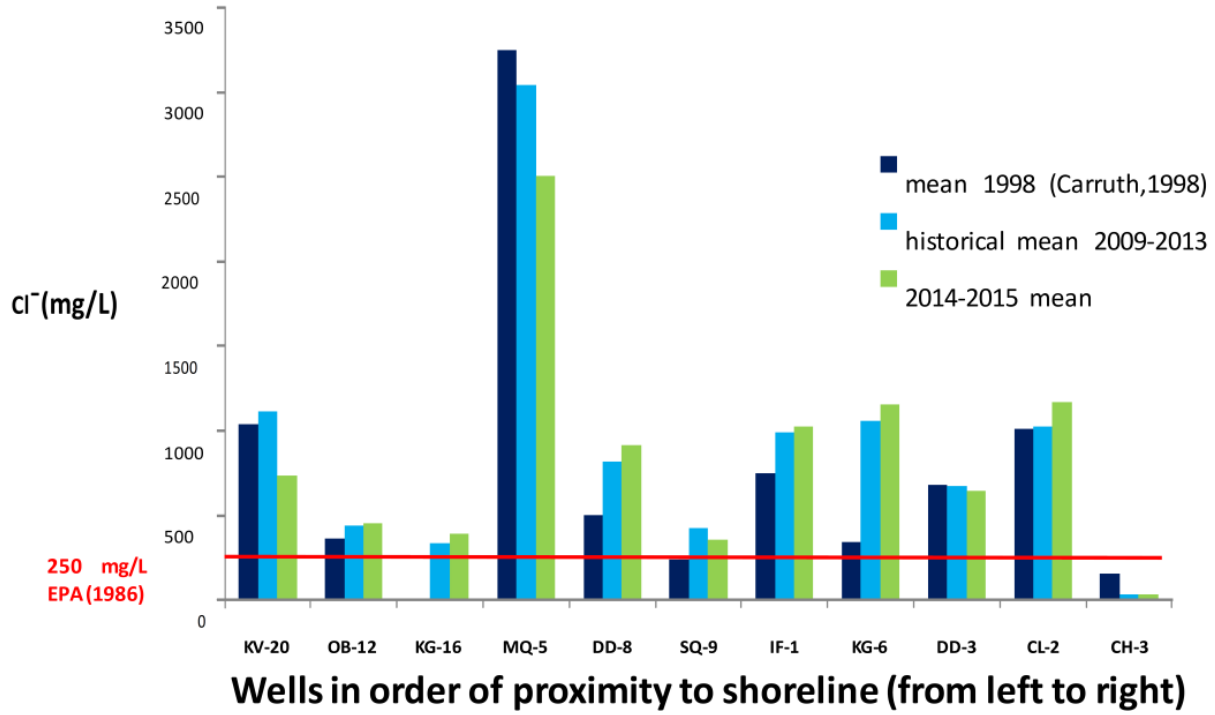

Figure 6. Mean chloride concentration for wells in order of proximity to shoreline (nearest left).

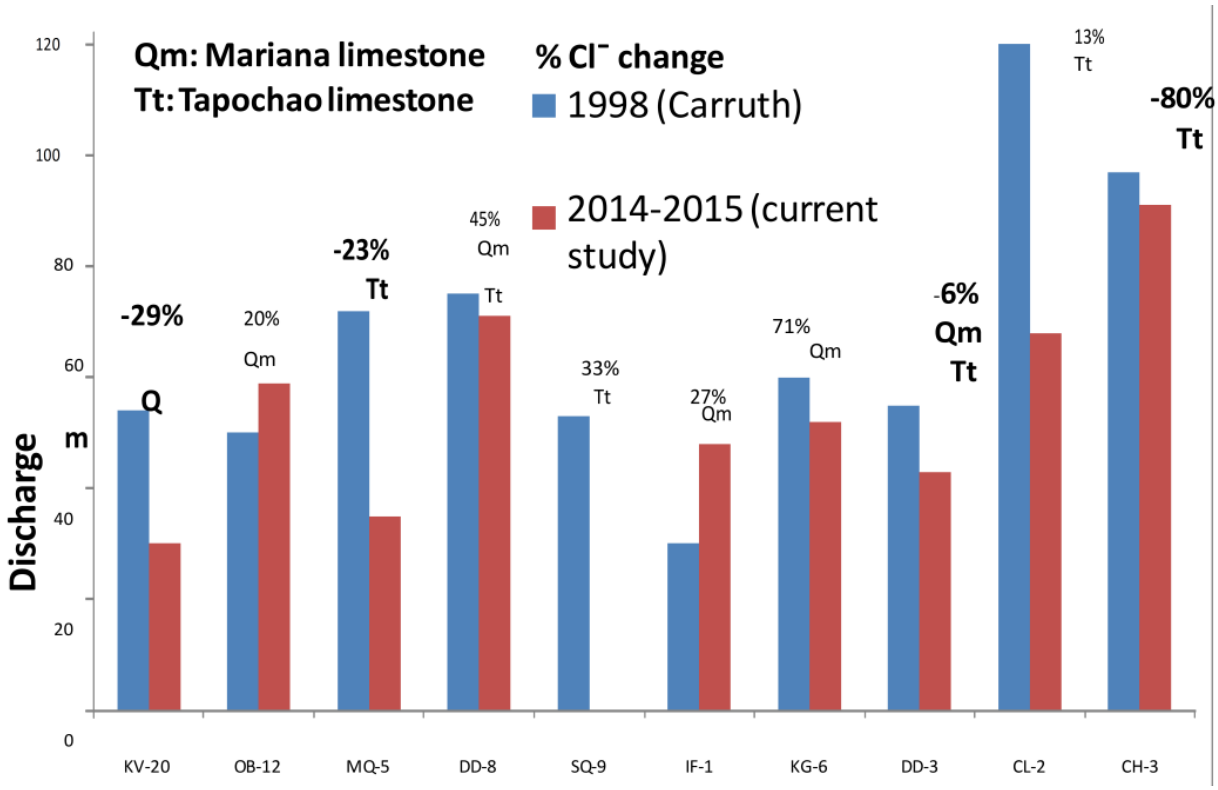

Figure 7. Well discharge rate for 1998 and 2014 with reported % change in chloride concentration and geologic formation.

wells, the quality of water pumped improved. At the same time the opposite has been observed (water quality decreased with lower pumping rates). This may indicate pumping rates need to be lowered even more, to allow for aquifer recovery. Discharge rates measured during this study range from 30 to 91 Gal/min.

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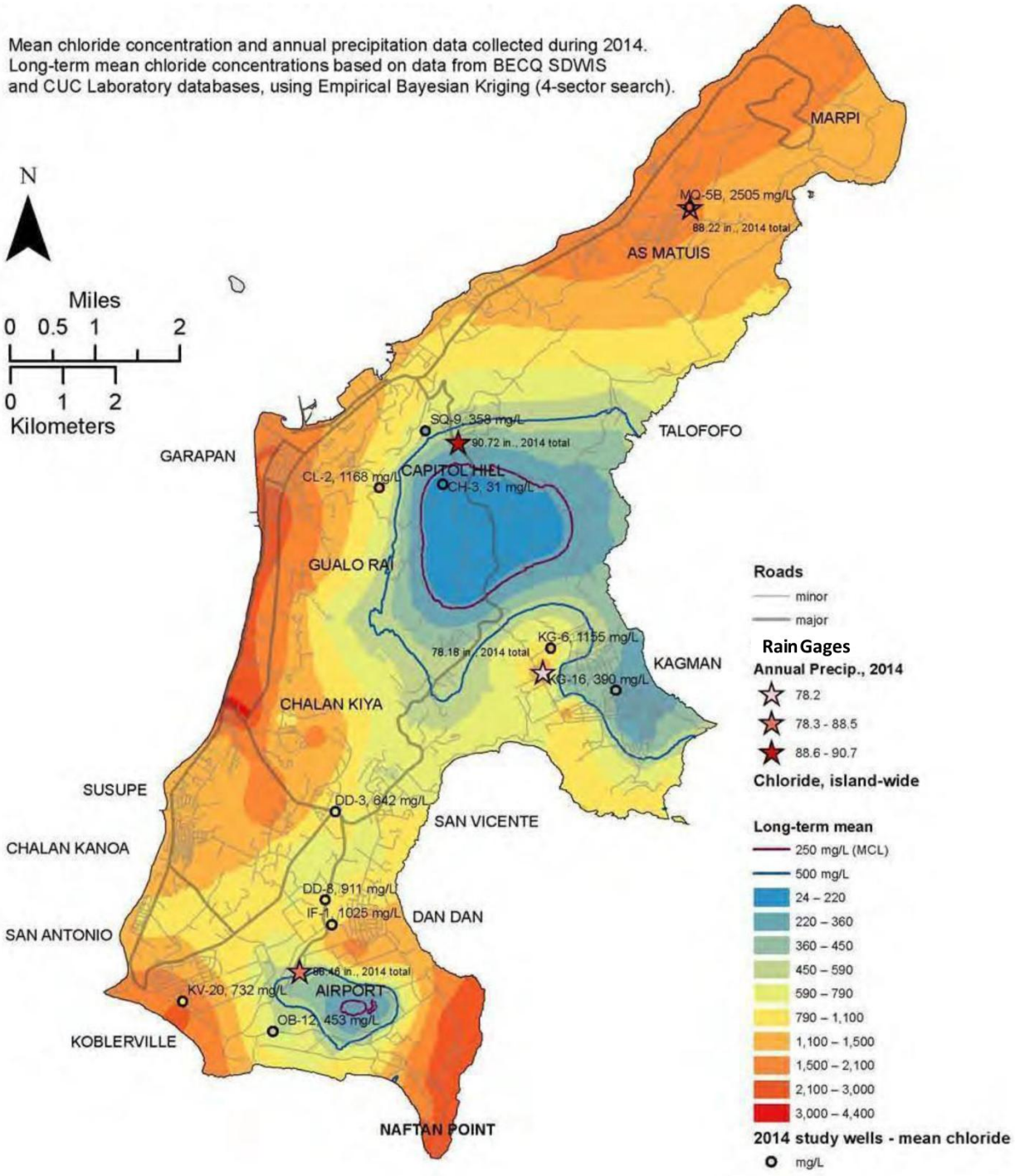
Figure 8. Chloride and precipitation 2014 to 2015.



Courtesy of Brian Bearden, PE

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Impact of Stormwater Discharges and WWII on the Mercury Status of Fish from the Southern Section of Saipan Lagoon

Basic Information

Title:	Impact of Stormwater Discharges and WWII on the Mercury Status of Fish from the Southern Section of Saipan Lagoon
Project Number:	2014GU275B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Non Point Pollution
Descriptors:	None
Principal Investigators:	Gary Denton

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Impact of Stormwater Discharges and WWII on the Mercury Status of Fish from the Southern Section of Saipan Lagoon

Problems and Research Objectives:
On July 15, 1944, several thousand US troops stormed the southern beaches of Saipan Lagoon to liberate Saipan from the hands of the Japanese who took control of the island shortly after WWI. Japanese defenses positioned along the coast were heavily shelled prior to the US invasion, as were US troops in the lagoon during the assault. While this historic battle unquestionably marked the turning point of WWII, it left behind a legacy of chronic environmental mercury contamination that still exists to this day.

The first hint of a potential mercury problem in this area emerged in 2007 when an independent research team reported frequent and occasionally high mercury detections in stormwater runoff discharged into the southern half of the lagoon between the villages of Garapan and San Jose. (Environ Inc., 2007). These findings were especially noteworthy because mercury is rarely encountered in urban runoff (USEPA, 1983). At about the same time, WERI researchers identified unusual mercury distribution patterns in sediments throughout the southern half of the lagoon that suggested inputs washed into the lagoon from land-based sources were superimposed upon a scattering of mercury contamination emanating from within the lagoon itself (Denton *et al.,* 2014). Since mercury was used extensively in WWII (as mercury switches in projectiles and rockets, and as the primary explosive, mercury fulminate, in primers and detonators of artillery shells and percussion caps of bullets) it was postulated that pockets of mercury contamination associated with exploding WWII ordnance and lost ammunition had been created along the coastal belt and in the lagoon.

Between 2004 and 2008, WERI examined mercury levels in popular table fish from approximately the same stretch of coastline as that visited by the Environet team in 2004 (Fig. 1, sites 1-5). The results of the investigation revealed a marked and irrefutable southerly increase in mercury levels in certain fish species (Denton *et al.,* 2010, Denton and Trianni 2011) sufficient to advise consumers against their unrestricted consumption (Bearden *et al.,* 2010). Considering the area further south in the lower section of the lagoon was subjected to the heaviest artillery bombardments, strafing, and small arms fire power during the US invasion (Crowl, 1960; Trueman, 2000), and also currently receives substantial stormwater runoff from the land, there was justifiable concern that mercury levels in fish from the latter region would pose the greatest public health risk to unwary consumers. The project described herein was implemented to examine this possibility.

Methodology:
Fish analyzed during this study were taken from seagrass beds of discrete zones bordering the southern half of Saipan Lagoon (Fig. 1) between Chalan Monsignor Guerrero Road (site 6) and Agingan Point (site 11). Two carnivorous emperor fish species (*Lethrinus harak* and *L. atkinsoni*) were of particular interest because of their restricted foraging ranges and popularity among local fishers. Boundary limits of each zone along this 4-km stretch of coastline were fixed by GPS and reference to prominent landmarks. Methods of capture employed spear-gun and

Hawaiian sling with the assistance of local personnel. Permits were obtained from the Saipan Division of Lands and Natural Resources (Division of Fish and Wildlife).

Mercury levels were determined in axial muscle taken from immediately below the dorsal fin of all specimens. Complete digestion of this tissue was achieved in a 2:1 nitric-sulfuric acid mixture at 100^{o}C, for 3 hours. Analysis was accomplished by cold vapor Atomic Absorption Spectroscopy using the syringe techniques described by Stainton (1971). Calibration standards (5–20 ng/L) were made up in 10% nitric acid containing 0.05% potassium dichromate as a preservative (Feldman, 1974). QA/QC procedures included blanks, matrix spikes, and accuracy and precision verifications using the albacore tuna standard reference material, RM 50. Mercury recoveries from this matrix were consistently better than 95%.

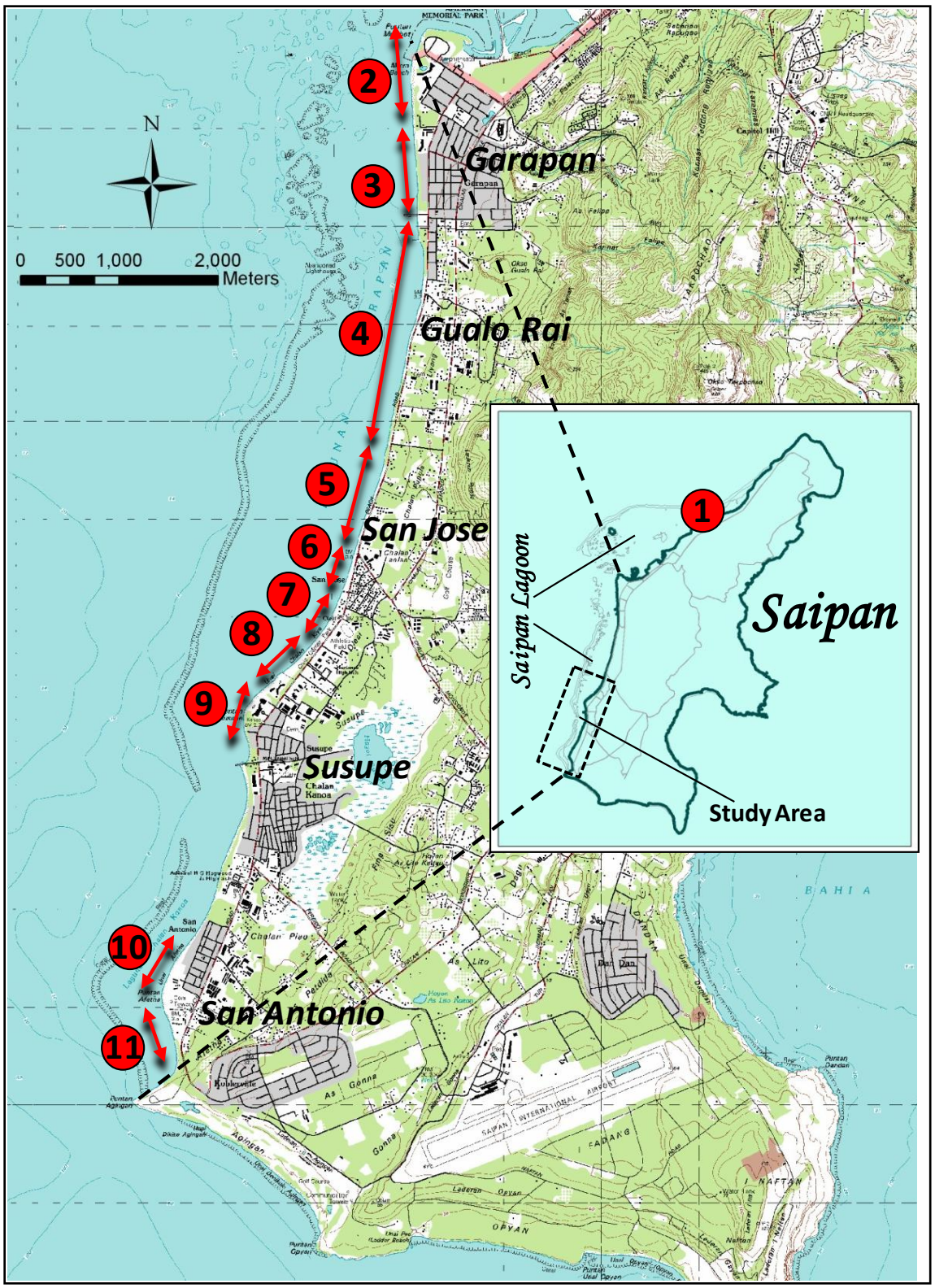

Figure 1: Map of Saipan showing emperor fish sampling sites in the large lagoon that borders the western side of the island. Mercury levels in specimens from sites 1-5 were determined in earlier investigations (Denton *et al.*, 2010; Denton and Trianni, 2011). The data are included in this report for comparative purposes. Fish from all other sites were collected for mercury analysis during the present study.

Principle Findings and Significance:
Mercury levels in axial muscle of fish from non-polluted waters typically range between 0.001-0.100 µg/g wet weight depending upon age and trophic level of representatives' examined (Holden 1973). All fish analyzed during the present study fell within this normal range in sharp contrast to several specimens collected earlier from some of the more northerly lagoon sites (Table 1). This discrepancy is partly due to a strong positive correlation between fish size and mercury concentration, plus the fact that generally larger fish were caught from the latter sites. Such inconsistencies can be accommodated by normalizing the data to a standard fish length using regression analysis. Since the relationship between fish size and mercury concentration is not linear, log-transformation of the datasets prior to regression is usually required. Mercury levels in fish from sites 1-11 in Saipan Lagoon were thus normalized to a standard 20 cm fish length. The results are illustrated graphically in Fig. 2 and clearly show that fish from sites 6-11 in the southern half of Saipan Lagoon contain lower mercury concentrations in their axial muscle when weighed against their northern counterparts.

Table 1: Total Mercury Levels in *Lethrinus* spp. from Saipan Lagoon (all sites examined to date)

Year	Location	Map Site No.	Fish sp (n).	Data Range (median)		X-Y Regression Coefficient (r)
				Fork Length (X) (cm)	Total Hg (Y) (µg/g wet wt.)	
2005 - 2007	Northern End of Saipan Lagoon	1	*L. harak* (20)*; L. atkinsoni* (1)	13.4-26.8 (21.3)	0.028-0.146 (0.069)	0.277
2005 - 2007	Micro Reef and Micro Beach	2	*L. harak* (20)*; L. atkinsoni* (3)	13.9-27.5 (21.7)	0.057-1.185 (0.128)	0.683*
2005 - 2007	Hafa Adai Beach to Small Boat Ramp	3	*L. harak* (24)*; L. atkinsoni* (5)	12.5-24.4 (19.2)	0.029-0.204 (0.068)	0.799*
2004 - 2008	Small Boat Ramp to 'Triple J' Motors	4	*L. harak* (9)*; L. atkinsoni* (1)	10.0-23.5 (19.7)	0.041-0.212 (0.069)	0.733*
2004	Triple J Motors to Microl Motors	5	*L. atkinsoni* (10)	16.7-21.6 (19.6)	0.144-0.276 (0.193)	0.793*
2014 - 2015	Zone A	6	*L. harak* (10)	13.5-20.8 (15.5)	0.022-0.079 (0.050)	0.682*
2014 - 2015	Zone B	7	*L. harak* (15)	12.5-21.0 (16.0)	0.017-0.053 (0.024)	0.755*
2014 - 2015	Zone C	8	*L. atkinsoni* (5)	18.0-22.2 (19.8)	0.020-0.077 (0.061)	0.772*
2014 - 2015	Zone D	9	*L. harak* (7)	13.0-20.3 (14.2)	0.019-0.040 (0.022)	0.429
2014 - 2015	Zone E	10	*L. harak* (10)	12.5-20.5 (13.9)	0.015-0.060 (0.021)	0.772*
2014 - 2015	Zone F	11	*L. atkinsoni* (8)	13.6-16.5 (15.5)	0.019- 0.029 (0.022)	0.407

*significant correlation (P<0.05 or better) between total mercury in axial muscle and fork length

The relatively high mercury levels in fish from site 2 are understandable given the close proximity of this site to the now closed Puerto Rico Dump and a post-war ordinance detonation and disposal facility located immediately behind Micro Beach. These adjacent lands are now occupied by the American Memorial Park (AMME), a 33 acre property that commemorates US soldiers who lost their lives during the Saipan invasion. In 2004, hundreds of unexploded ordnance were unearthed during the construction of the AMME Visitor Center car park. A magnetometer sweep suggested hundreds more remain buried outside of the construction area (AMPRO 2005). Although moderate mercury contamination is known to exist in surface soils within the park grounds (Denton, unpublished data), the ongoing impact of these post-war activities on mercury levels in nearshore fisheries has yet to be evaluated.

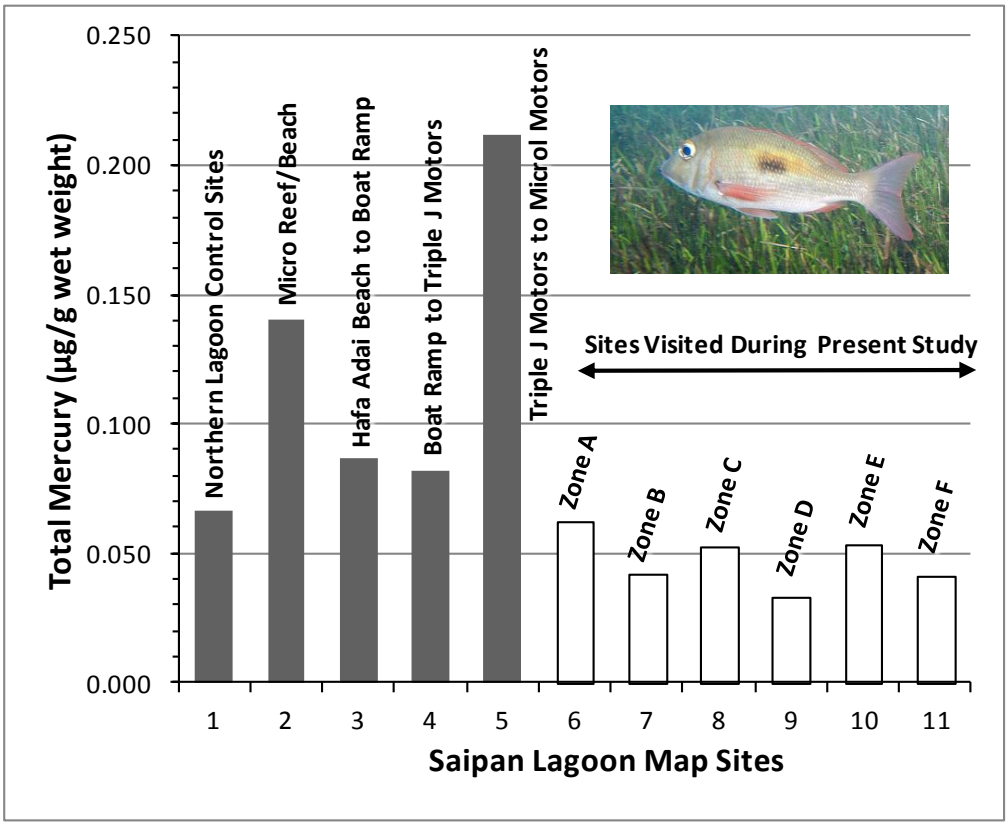

Figure 2: Total mercury levels normalized to a standard 20-cm fish length for all sites in Saipan Lagoon. Inset photo of *Lethrinus harak* feeding among *Halodule* seagrass beds.

The normalized mercury level recorded in fish from site 5 (0.211 µg/g wet weight) is quite remarkable and flags the almost certain existence of a localized mercury 'hot spot' somewhere along this ~1 km stretch of coastline. Studies are currently underway to track down the source of this element and delineate the extent of its impact on fisheries within the site zone.

Public health risks associated with eating mercury contaminated fish are exacerbated by the fact that this element is predominantly present in the highly toxic, methylated form (Storelli *et al.* 2005). USEPA fish consumption guidelines for the general population recommend that fish with methylmercury concentrations in their muscle tissue above 0.088 µg/g wet weight should not be eaten on an unrestricted basis (USEPA 2000). Based on this assumption, an 8-oz meal of 20-cm emperor fish from site 5 should not be eaten more than three times per week.

Because of uncertainties associated with the formulation of USEPA risk-based consumption limits for mercury in fish, risk managers in the US have some degree of flexibility in setting State fish advisories and do not always strictly adhere to USEPA guidelines. The Iowa Department of Public Health, for example, decrees that all fish containing <0.3 µg/g mercury are safe to consume with no meal restrictions. Consumption of up to one 8-oz meal per week of fish containing 0.3-1.0 µg/g of mercury is also considered safe while fish containing over 1.0 µg/g of mercury should not be eaten at all. If Saipan were to adopt a similar policy then all emperors analyzed here would fall into the unrestricted consumption category, with the single exception of one 26.3 cm specimen of *L. harak* taken from Micro Beach in 2005 (1.180 µg/g wet weight).

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Optimizing operation of the Saipan's water distribution system using diurnal demand pattern and system pressure

Basic Information

Title:	Optimizing operation of the Saipan's water distribution system using diurnal demand pattern and system pressure
Project Number:	2014GU276B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	None
Principal Investigators:	Brian Bearden, Shahram Khosrowpanah

Publication

1. Khosrowpanah, Sh., Brian Bearden, 2014, Optimizing Operation of the Saipan's Water Distribution System using Diurnal Demand Pattern and System Pressure (Abstract) , Annual General Meeting, Asia Pacific Academy of Science and Environmental Management, American Memorial Park Auditorium, Saipan, November 18-20, 2014.

PROJECT SYNOPSIS REPORT

Project Title: Improving Saipan's Water System Operation

Problem and Research Objectives:
A stated goal of the CNMI government is to provide 24-hour water to all residents served by the Commonwealth Utilities Corporation (CUC). In response, for the past several years the Saipan water delivery system has undergone significant changes. In 2006, the EPA acknowledged that the lack of safe drinking water was among the top environmental challenges facing the CNMI, particularly Saipan (Erediano, 2006). As the result, in March of 2009, the Commonwealth Utilities Corporation (CUC) entered into a stipulated order (SO) for preliminary relief under an agreement with the Government of the United States. The order provided for a long list of compliance items that CUC must complete in order to satisfy the stipulated order. One major item that CUC must prepare is a Master Plan for their water supply and waste water systems. In 2013 the draft master plan was submitted for EPA review, and an updated plan addressing EPA comments is under development and due to be submitted in May, 2015. The master plan includes an assessment of the current state of the water infrastructure and provides recommendations for improvement. Reducing system losses (non-revenue water), eliminating negative pressures (a consequence of non-24 hour service), and monitoring water usage were on the high priority list that was recommended to CUC for improvement. According to the draft master plan, non-revenue water accounts for nearly 70 percent of the water production on Saipan. Assessing various strategies for reducing non-revenue water and providing 24-hour water was identified as one of critical research needs at the CNMI research advisory meeting of October 17, 2013.

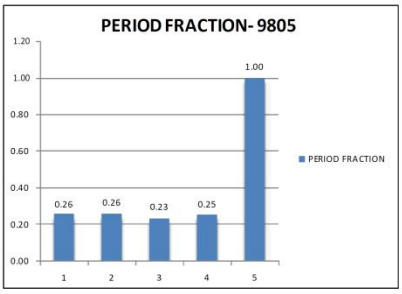
To improve the system operation and reduce the non-revenue water requires having a good knowledge of the pressures in the water system and how this changes with time. During FY 2013, the project investigators installed water meter loggers that recorded hourly water use. They developed hourly water use for residential areas shown in Figure 1.

This project represents the next step and installed pressure loggers throughout the system. Pressure is a valuable system operational parameter because it serves both as an important indicator of demand, as well as an indicator of tank level and operational challenges such as line breaks, valve operation (water supply diversions), and other losses. The specific objectives of this project were to:

1. Determine the pressure change throughout the CUC's water distribution system using pressure loggers that will be installed at selected points throughout the system.
2. Continue to improve diurnal demand pattern (changes of water demand during the day and month) that was developed in FY2013.
3. Examine the physical components of the entire water distribution system
4. Optimize water system operation to assist CUC in providing 24-hour water service to all its customers.

Figure 1. Daily Residential Water use, as developed during the FY 2013 .

Total Gallons = 40700
Average GPD = 237.38
Gal/Person/Day = 118.7



PERIOD TIME	AVERAGE GALLONS	AVERAGE GPM	PERIOD FRACTION
1 TO 6	60.92	0.17	0.26
7 TO 12	61.70	0.17	0.26
13 TO 18	54.70	0.15	0.23
19 TO 24	60.02	0.17	0.25
	237.35		1.00

Methodology

To accomplish the stated objectives, six pressure loggers were installed throughout select portions of the Saipan CUC water system shown in Figure 4. The pressure logger types that were used: Fire hydrant type: Global Water model PL-200-H-1, and Hose bib type: Global Water model PL-200-Gas as shown in Table 1, Figures 2 & 3.

Data was validated through the use of a field pressure gauge with a hose bib-type connection, used to check pressure readings at the point of connection (or at a nearby residence in the case of the fire hydrant logger). In all cases, the factory-calibrated pressure logger data was within 1 to 3 psi of gauge pressure, so no additional calibration was performed. Data collection was performed periodically in the field with a laptop PC using the Global Logger II software program provided with the pressure loggers.

Table 1: Pressure Logger locations and data collection periods.

Loggers Installed					
No.	Logger type	Date Installed	Period of valid data	Location	Customer
FH-1	Fire hydrant	4/22/14	4/22/14 to 4/28/14	Suni Ln.	Muna
FH-1	Fire hydrant	6/13/14	6/13/14 to 3/26/15	Airport Rd	
1	Sample tap/hose bib	6/13/14	6/13/14 to 9/12/14	Swimming Ln.	Guerrero
2	Sample tap/hose bib	6/13/14	6/13/14 to 9/12/14	Tun Kioshi Rd.	
3	Sample tap/hose bib	6/13/14	6/13/14 to 6/30/14	Bagasu Ln.	Castro
4	Sample tap/hose bib	6/13/14	6/13/14 to 10/13/14	Chalan Msgr. Martinez	Flores
5	Sample tap/hose bib	5/12/14	6/13/14 to 8/31/14	As Lito Dr.	Bearden

Figure 2: Fire hydrant type pressure logger


Figure3. Hose bib-type pressure logger

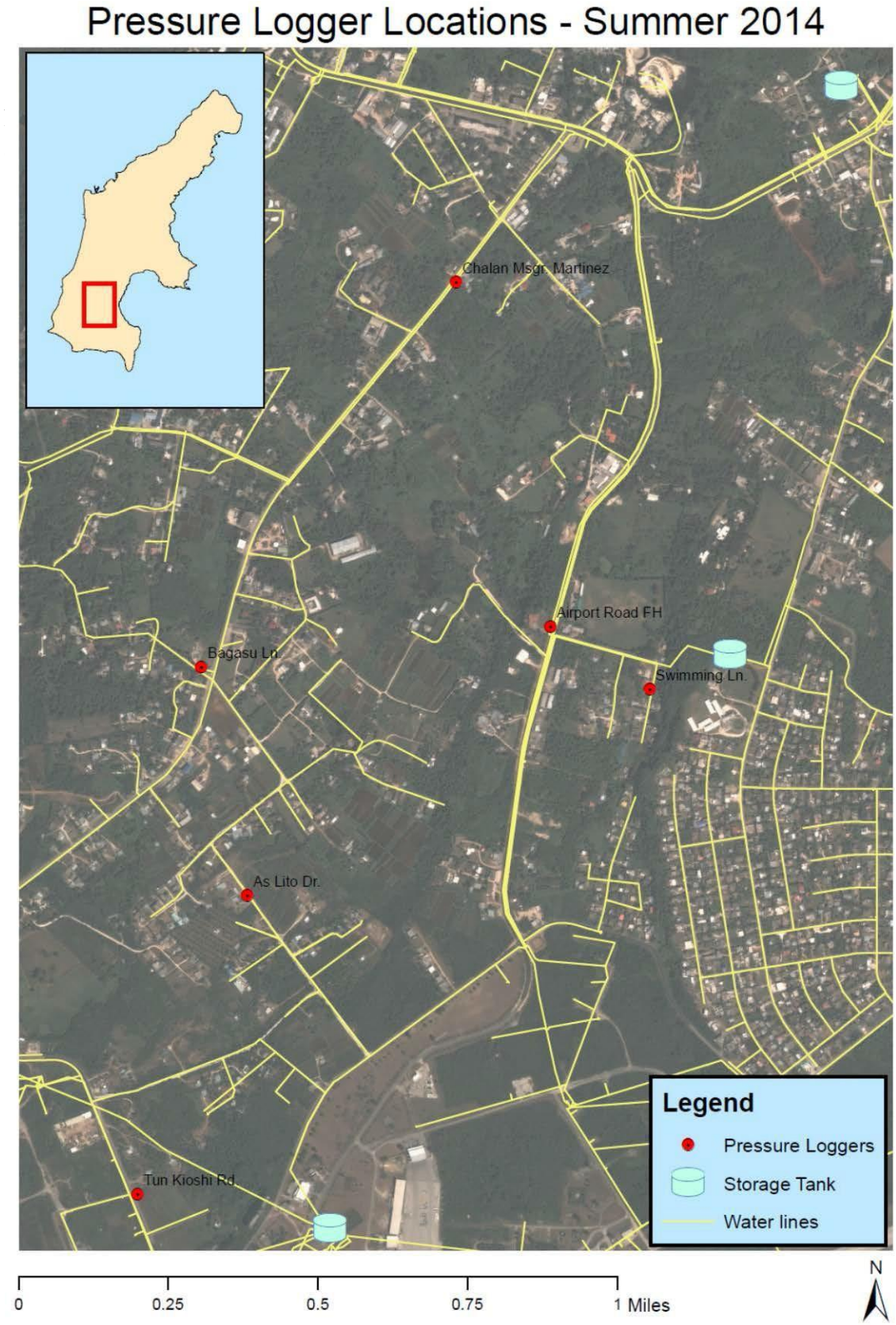


Figure 4. Pressure logger locations within Dan Dan / As Lito study area.

Principal Findings and Significance:

Daily pressure profiles

Average daily pressure profiles were generated for each logger location using the longest period of reasonably stable pressure available. In some cases this was about 1 week, and in other cases close to a month of data was available. Figure 5 shows the pressure profiles of all sites except Bagasu Lane, for which a meaningful profile could not be generated due to the extreme pressure changes caused by the "Water Watch" operations and the short period of data collection prior to logger failure.

Four of the sites showed a distinct residential pressure profile, corresponding to the residential demand pattern generated by the FY 2013 project. These sites were the Muna residence, Bearden residence, Chalan Monsignor Martinez, and Tun Kioshi Road. Data from these sites were combined to create the average residential demand profile shown in Figures 6. The daily pressure profile for these sites exhibit strong peaks in demand (corresponding with reduced pressures) in the morning and evening, consistent with typical residential demand patterns. Figure 7 compares the daily flow demand profile generated in the FY 2013 project with the pressure demand profile generated by this project. The profiles match closely in shape, but the timing of the peak flows is different. This is probably the result of demographic differences among households in the different study areas.

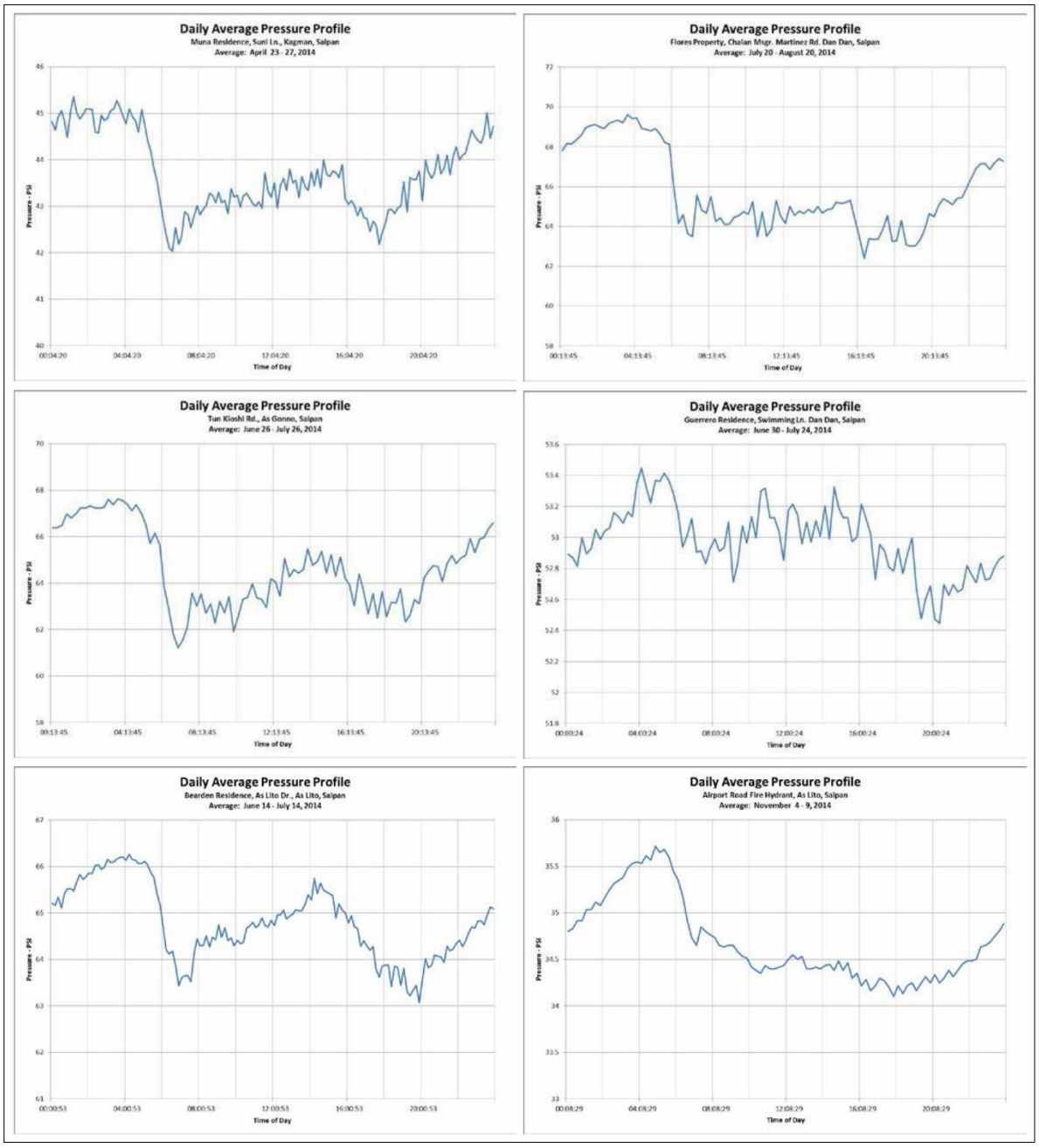


Figure 5. Average daily pressure profiles for all sites.

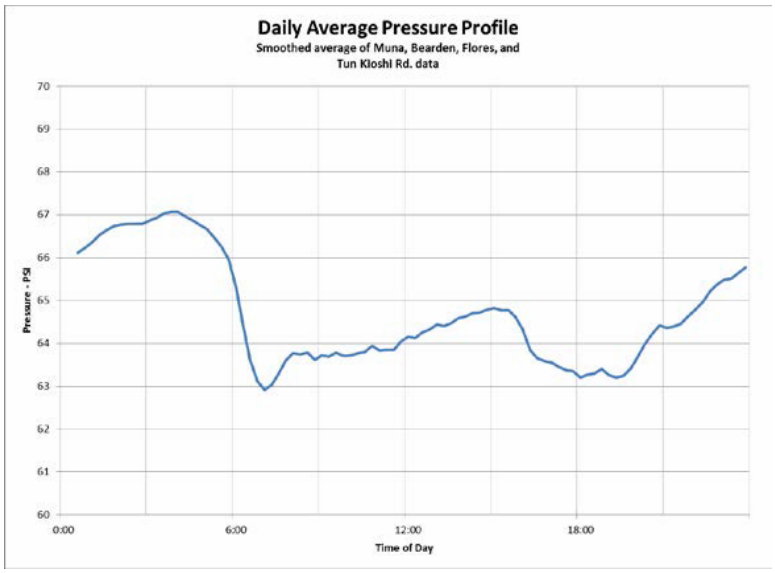
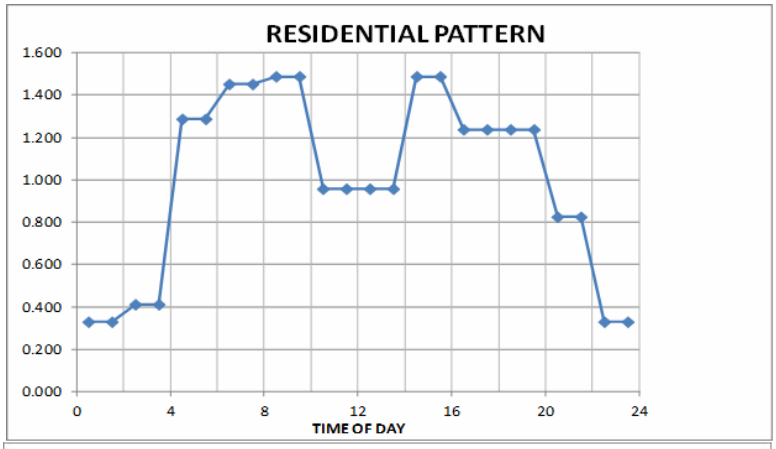


Figure 6: Average Daily Pressure for selected sites.



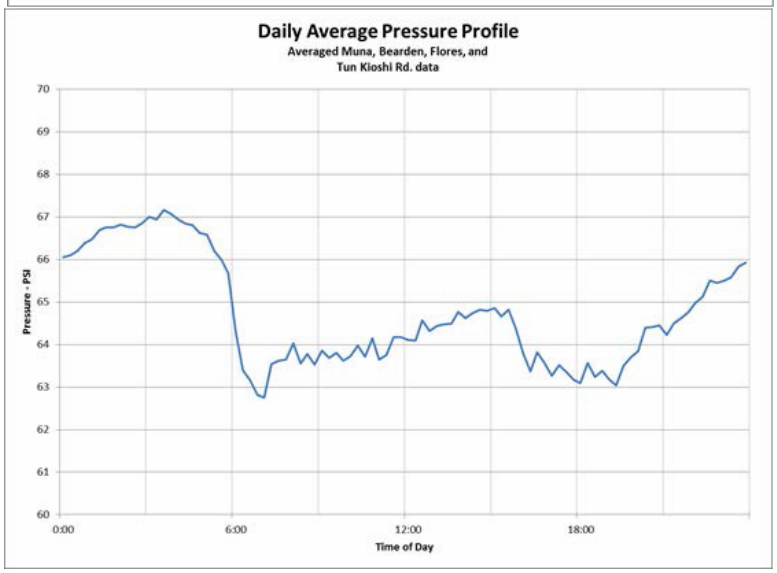


Figure 7: Comparison of daily average residential flow demand profile and daily average residential pressure

Weekly pressure profiles

Examination of the longer-term data records revealed some patterns beyond the daily pressure profiles generated by residential and commercial water use. The Bearden residence data, for example, exhibited a strong weekly signal indicative of a 5-day work week, with the usual peak flows occurring early morning and evening for the period of Monday through Friday, while losing the morning peaks on the weekends (Figure 8).

Dry and rainy season effects

The longer term records also indicated some possible effects of dry and rainy periods on water demand. Figure 8 shows measured system water pressure at the Tun Kioshi Road location, with the average water pressure generally tracking the quantity and pattern of

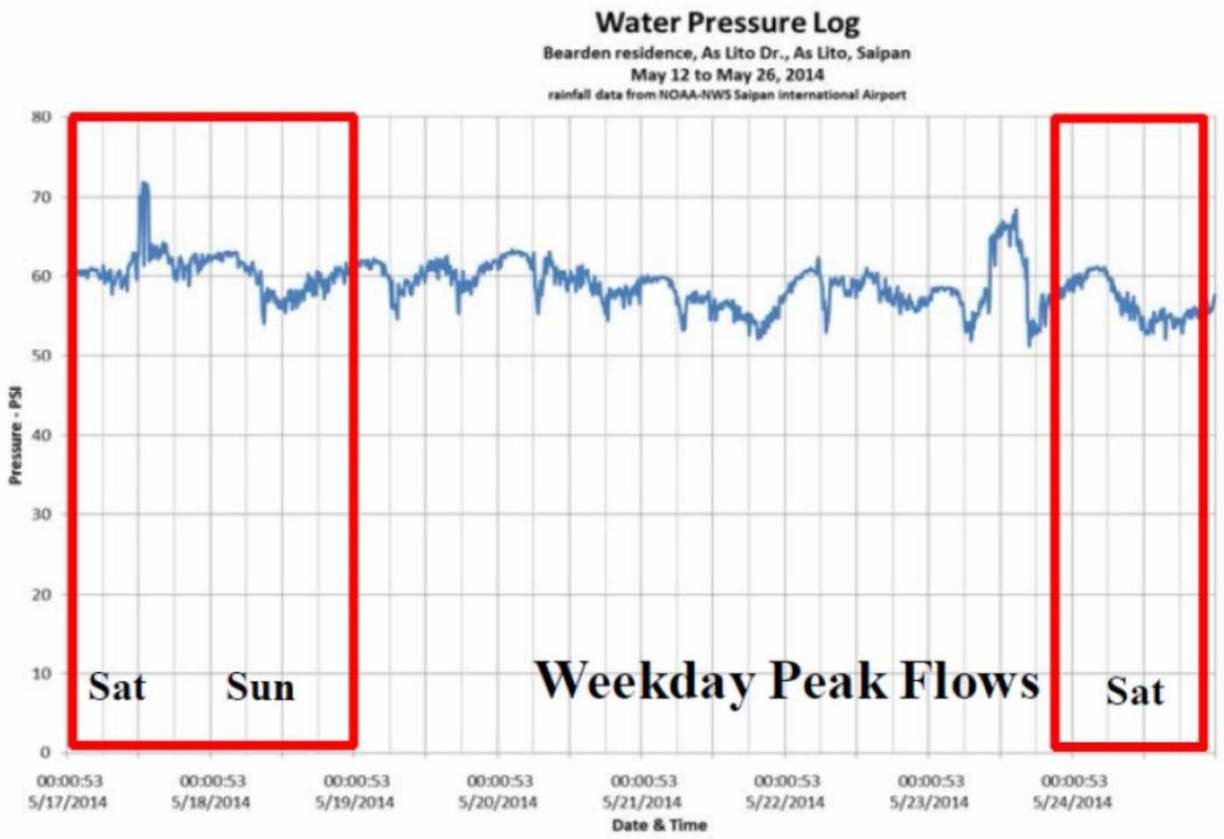


Figure 8: Weekly residential patterns exhibiting lack of morning peak demand on weekends (box in red).

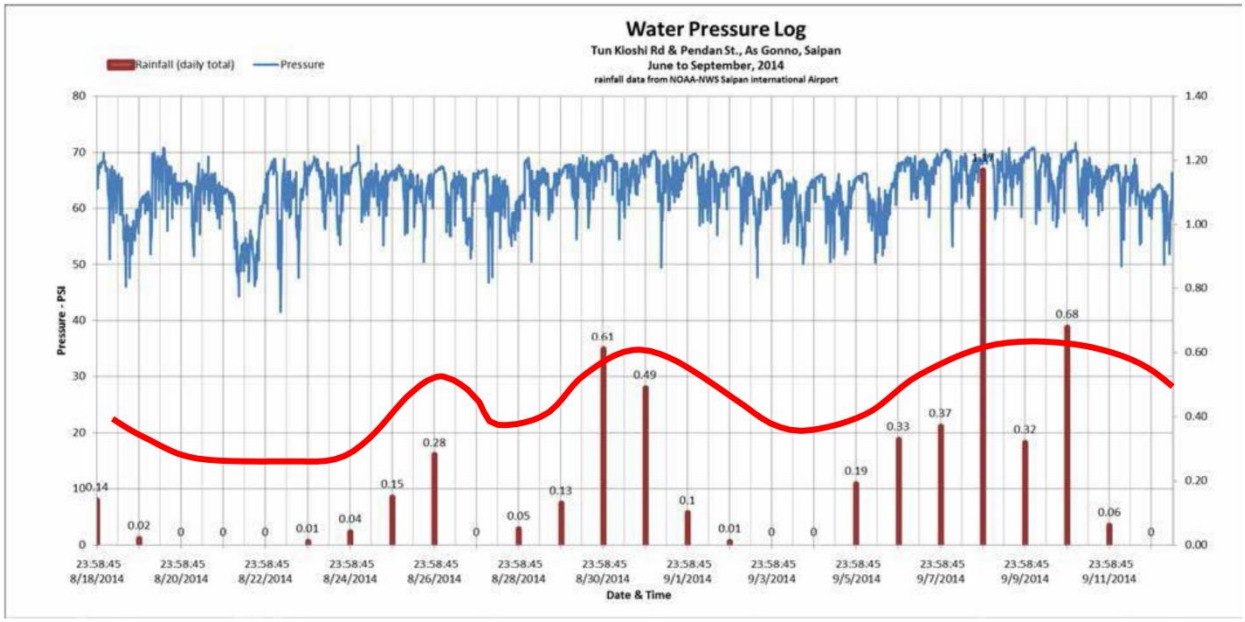


Figure 9. Comparison of pressure to daily rainfall exhibiting possible correlation

rainfall (the red curve is hand drawn to illustrate generalized trend of rainfall, shown as bars on chart.) As discussed previously, periods of lower pressure are either caused by reduced water levels in the storage tank serving the area, or friction loss caused by increased flow through the distribution pipes, indicating an increase in demand. Tank level changes are generally a daily variable. The longer-term and more gradual undulation in system pressure shown in Figure 9 is likely the result of changes in demand (flow).

Possible explanations for why demand seems to follow rainfall in this area include agricultural use and residential rainwater catchments. Agricultural use, or irrigation, is likely to decrease during periods of wetter weather, which would result in decreased flows and therefore increased system pressure. Similarly, residences which utilize rainwater catchments to supplement CUC for their source of domestic water are likely to withdraw less water from CUC during rainy periods, resulting again in higher system pressures. The area surrounding the Tun Kioshi Road logger has a number of farms in addition to scattered residences, so it is possible that the observed system pressure response is a combination of both factors.

CONCLUSIONS

Excellent data characterizing daily residential demand was collected and used to generate a daily residential pressure profile, which mirrors the daily demand profile generated by the FY 2013 project well in terms of shape, but differs in terms of the timing of the early morning and evening peak demands. One site yielded a different demand profile that appears to be indicative of commercial demand. The data showed some interesting results in terms of pressure change patterns, especially results that seem to correlate rainfall to system pressures. In most locations that were monitored, periods of reduced rainfall corresponded to periods of reduced system pressure, indicating increased demand during these periods. This could possibly be explained by both agricultural use and the use of customer rainwater catchments. Agricultural use is suspected of causing the most significant effects to system operations, with wide swings in tank levels shown during some dry periods, which cannot be explained by any other use or system operational setting. The data showed some interesting results in terms of pressure change patterns, especially results that seem to correlate rainfall to system pressures. In most locations that were monitored, periods of reduced rainfall corresponded to periods of reduced system pressure, indicating agricultural use and the use of customer rainwater catchments. Agricultural use is suspected of causing the most significant effects to system operations, with wide swings in tank levels shown during dry periods, which cannot be explained by any other use or system operational setting. The data showed some interesting results in terms of pressure change patterns, especially results that seem to correlate rainfall to system pressures. In most locations that were monitored, periods of reduced rainfall corresponded to periods of reduced system pressure, indicating increased demand during these periods. This could possibly be explained by both agricultural use and the use of customer rainwater catchments.

Agricultural use is suspected of causing the most significant effects to system operations with wide swings in tank levels shown during some dry periods, which cannot be explained by any other use or system operational setting. Finally, pressure logger data proved to be valuable in optimizing water system operations. In one case, system operators were unaware of the wide swings in pressure that the “Water Watch” daily valve-adjustments were causing, and they were then able to tune these adjustments to provide much more consistent pressures and 24-hour service to an area that had previously been more poorly served.

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Pilot study to improve wastewater treatment system in Yap, FSM

Basic Information

Title:	Pilot study to improve wastewater treatment system in Yap, FSM
Project Number:	2014GU277B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Engineering
Focus Category:	Wastewater, Treatment, Methods
Descriptors:	None
Principal Investigators:	Joe Rouse

Publication

1. Joseph D. Rouse, 2015, Survey of Wastewater Treatment Practices in the Federated States of Micronesia with a Focus on Pilot Testing in Yap. First Annual Conference, American Water Works Association, Hawaii Section, Western Pacific Sub-Section. Hyatt Regency, Tumon, Guam; April 13-14, 2015.

PROJECT SYNOPSIS REPORT

Project Title: Pilot study to improve wastewater treatment system in Yap, FSM

Problem and Research Objectives:
Inadequate treatment of domestic wastewater (sewage) in the Pacific Islands has been responsible for serious environmental and human health problems due to damage to the natural environment and contamination of water supplies. The reason for this can often be attributed to a lack of functional technology due to inadequate funding for both capital investments and ongoing O&M expenses. On Yap Island in the Federated States of Micronesia (FSM), over 300 households are connected to the centralized sewage treatment plant (STP) in Colonia, but the treatment being provided is clearly insufficient with nearly raw sewage being discharged via a short outfall to the shallow ocean bay near the business center.

The existing STP is an Imhoff-tank system with two parallel treatment lines, which by design provides little more than removal of easily settleable solids, or a primary level of treatment. An upgrade to a secondary level of treatment, providing additional biological treatment power for removal of most soluble organic compounds, would require a major capital investment and be met with higher O&M costs as well, including treatment and disposal of increased amounts of excess sludge. However, the possibility exists of inserting a framework fitted with a net for biofilm attachment into a concrete basin of the existing STP. This could serve as a biocarrier, which would allow for retention of beneficial biomass and provide the potential for enhanced treatment efficiency.

The nature of the project proposed here is that of conducting a pilot test, including collecting samples and analyzing data to evaluate the results of the test. The conceptual scope of the project will consist of making improvements to a STP. The physical scope of the project will be limited to the site of the STP in Colonia Town on Yap Island. The objective of the proposed project is to evaluate the application of an attached-growth process to the existing primary treatment system. This will be met by fitting frames covered with biocarrier net material to the flow channel of one of the existing Imhoff tanks and quantifying COD removals over time.

Methodology:
The methods used over the course of this project incorporated civil engineering fieldwork and water quality laboratory analyses. The work was carried out under the supervision of the PI and the Manager of the Water and Wastewater Division of the Yap State Public Service Corporation (YSPSC).

The biocarrier net material was selected and purchased by the PI in Guam and delivered to YSPSC in Colonia, Yap State. With assistance from personnel of the Water and Wastewater Division, six (6) frames for supporting the net material were constructed out of PVC pipe and fitted into the flow channel of one of the Imhoff tanks. Analyses were then performed on influent and effluent samples by local staff under the direction of the PI.

As an aggregate indicator of the quantity of organic compounds in the sewage, chemical oxygen demand (COD) was used, the analysis of which required a significant part of the project's budget. The manganese (Mn) method of COD determination was employed, rather than the more universally accepted chromium (Cr) and cadmium (Cd) methods, because the Mn-based procedure does not generate a hazardous-waste byproduct that would require expensive and difficult disposal methods in accordance with international standards.

Principal Findings and Significance:

The main wastewater treatment plant on Yap, though well functioning, provides only primary treatment consisting of a limited removal of suspended solids. Thus, to explore the possibilities for achieving a higher degree of treatment, a pilot test was initiated using an attached-growth process consisting of a mesh material fixed to frames inserted into the treatment channel for retention of beneficial biomass. The Imhoff-tank system under ordinary flow conditions is shown in Figure 1 and an empty tank showing where the pilot process could be inserted is shown in Figure 2. The design of the PVC-pipe frames used for attachment of biocarrier material is shown in Figure 3 and the first completed frame positioned in one of the Imhoff tanks is shown in Figure 4. After insertion of the completed complement of frames (Figure 5), wastewater was then directed to flow through the pilot test configuration (Figure 6).

Figure 1. Imhoff tank system under ordinary flow conditions.

Figure 2. Empty tank where pilot test unit could be inserted.

Following the sampling stations depicted in Figure 7, initial results as shown in Table 1 indicate reductions in COD levels ranging up to 60% across the treatment line containing the biocarrier framework. However, the influent COD levels monitored from June through December 2014 varied from more than 1000 mg/L to less than 200 mg/L, evidently due to storm-water intrusion, making it difficult to interpret the data. At the end of that period, a visual check was made of one biocarrier frame confirming a healthy growth of biofilm on the biocarrier material (Figure 8).

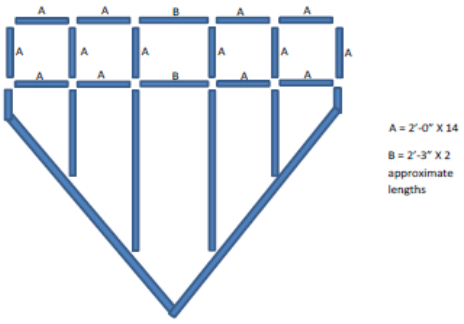


Figure 3. PVC-pipe framework for biocarrier medium.

Figure 4. First frame with medium attached inserted in Imhoff tank.

Figure 5. Full complement of six biocarrier frames in the Imhoff tank.

Figure 6. Normal operation with waste-water flowing through frame maze.

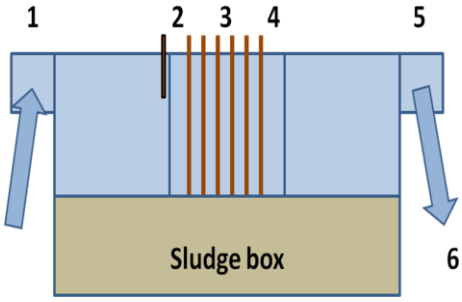


Figure 7. Sampling stations across the length of the Imhoff tank. Biocarrier frames are between stations 2 and 4.

Figure 8. Biocarrier after six months of use showing biofilm growth.

Table 1. Time courses of COD data across the biocarrier pilot test system for. Station numbers are identified in Figure 7.

2014	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
6/12		572		546	
6/13	1087	551		594	487
6/14	1255				742
6/15		773		746	829
6/16	757	735		789	
6/17	1012	763		732	818
6/23	750	306	324		
7/4	158	99	123	100	133
7/11	1015				403
7/18	139	123		101	115
7/25	173	97		93	94
8/1	378	386		319	309
8/12	230	171		153	198
8/22	357	262		225	200
9/5	62	5		107	53
9/25	511				415
10/17	101	59		39	120
12/9	308	209		226	226

Subsequently, as shown in Table 2, COD levels in the parallel channel without the biocarrier monitored from January through March 2015 were more consistent, demonstrating COD removals in the range from zero to 30%. However, data suitable for making statistically significant comparisons with the pilot test results (Table 1) are yet lacking. With data collection still in progress (as scheduled for FY 2015), a more complete picture of treatment performance, expanded to include nitrogenous compounds, will become evident. It is hoped this will allow for a decision to be made as to whether or not addition of more biocarrier material to the existing units would be beneficial. Such an endeavor would have the potential of improving the quality of water in the shallow bay where the wastewater is discharged.

Table 2. Time courses of COD data across the tank without the biocarrier pilot test, which define the base-line conditions. Station numbers are identified in Figure 7.

2015	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
1/23	331	273			234
1/30	328	290			285
2/6	256	272			254
2/11	330	300			340
2/13	297	305			295
3/27	355	425			383

Evaluating rainfall variability and drought thresholds for atolls and high islands of the FSM

Basic Information

Title:	Evaluating rainfall variability and drought thresholds for atolls and high islands of the FSM
Project Number:	2014GU278B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Drought, Water Quantity
Descriptors:	None
Principal Investigators:	Mark Lander, Shahram Khosrowpanah

Publication

1. Lander, Mark, Sh. Khosrowpanah, 2014, "Drought in the Western Pacific: a worrisome persistent long-term drying trend continues unabated for at least 60 years", Proceeding of 2014 UCOWR/NIWR Annual Conference, Medford, Massachusetts, July 18-20, 2014.

PROJECT SYNOPSIS REPORT

Project Title: Evaluating rainfall variability and drought thresholds for atolls and high islands of the FSM

Problem and Research Objectives:
All states of the FSM are vulnerable to damaging drought conditions, despite high average annual rainfall amounts (e.g.,Yap Island = 120 inches, Chuuk Airport = 135 inches, Kolonia, Pohnpei = 185 inches, and Kosrae Airport = 205 inches). In the first few months of the calendar year that follows a strong El Niño, the rainfall across all of Micronesia tends to be well below normal. Sharply reduced rainfall can quickly become a life-threatening emergency as reservoirs and rain catchment systems run dry, and agricultural plants are damaged. This is especially true on atolls where the water lenses are thin and rain catchment is a prominent source of drinking water. Micronesia-wide severe droughts in 1983, 1992 and 1998 required the deployment of U.S. military assets to the islands of the FSM to help transport and generate drinking water supplies. Recently, a more localized severe drought occurred in the northern atolls of the Republic of the Marshall Islands. This drought was so severe over the first few months of 2013 that on 14 June, U.S. President Obama declared a disaster for the RMI, authorizing additional U.S. Government funding for relief and reconstruction. Another recent local severe drought occurred on the atoll of Kapingamarngi (Pohnpei State) where rainfall during the six-month period beginning in September 2010 through February 2011 was only 7.12 inches, or 7% of the normal 48.37 inches. These dry conditions at Kapingamarangi and at other islands close to the equator (e.g., Tarawa and Nauru) are thought to have occurred because of a La Niña-related westward extension of cold sea surface temperatures along the equator. Small personal distillation units from government and non-government sources and reliable water shipments by the FSM and Pohnpei State governments averted a likely disaster.

Objectives: The objectives of this project are to:

(1) compile as much of the FSM climate record as possible from the first order stations and the growing network of outer island stations;
(2) analyze the climate records to provide a detailed picture of El Niño-related drought, and the nature of more localized droughts;
(3) establish impact thresholds during periods of reduced rainfall; and,
(4) develop an outreach itinerary for group discussion of drought during FSM visits.

Methodology:
The project PI has a good working relationship with all FSM weather officer staff and managers. He also works closely with NOAA's Guam Weather Forecast Office Warning Coordination Meteorologist. This allows the project PI to have access to the most complete set of climate records available in the FSM. The project PI is a member of the Pacific ENSO Applications Climate (PEAC) Center, with ongoing duties to provide operational long-range climate forecasts to Guam, the CNMI, FSM, Palau, the RMI, and American Samoa. NOAA is currently attempting to place the U.S.-affiliated Pacific Islands onto the U.S. National Drought Monitor. The information gathered in the proposed project will help to inform the organizers and authors of the Drought Monitor. It is a U.S. government statutory requirement that USDA drought assistance must be preceded by mention in the Drought Monitor. The U.S.-API qualify for such aid, and the project PI will be working closely with the local weather office and NOAA's drought monitoring program to develop drought thresholds and associated impacts to inform NOAA's inclusion of the FSM and other U.S.-API in the Drought Monitor.

It was envisioned that the principal accomplishment of this project would be the development of a comprehensive set of outreach products (study guide, technical report, Powerpoint presentation) to form the backbone of informative seminars regarding drought, the impact of drought and climate change scenarios for each of the FSM states. During the first outreach visit of the project PIs in the fall of 2014, the knowledge base will be refined from feedback with FSM water resource managers. The final set of outreach projects containing the final published WERI technical report will be ready by the end of the project period (February 2015).

Principal Findings and Significance:
The investigation of drought in the FSM is ongoing, and a great effort is being undertaken to gather relevant climate data, and assessment of the impacts of drought. The data gathering effort is through collaboration with several partners:
(1) National Weather Service Forecast Office, Guam (Chip Guard);
(2) UOG Sea Grant Program (Dr. Laura Biggs);
(3) The National Climatic Data Center (Richard Heim);
(4) The Pacific ENSO Applications Climate Center (Dr. Mark Merrifield, UH Manoa JIMAR)
(5) The Pacific Islands Climate Science Center (Dr. David Helweg, UH Hilo)

Working with Chip Guard for the past 20 years, the project PI has assembled the most complete record of U.S.-affiliated Pacific Island rainfall data in existence. We have carefully collected and archived rainfall from all the first-order stations, and have worked with the FSM weather personnel to obtain and archive the several second-order stations form each of the island groups. In many cases, we have made edits to the data for missing typhoons, and other cases. The second-order stations now have up to 20 years of continual data, some with notable gaps. The project PI in collaboration with Mr. Guard, are readying much of this data for eventual inclusion into the archives of the National Climatic Data Center. An example of this effort is the following chart (Figure 1) of rainfall for the islands of Utirik and Wotje in the Marshall Islands. Although there are many gaps in each record, the project PI was able to work out a long term time series for each atoll, establish the annual mean, investigate the long-term trend, and establish the bounds of season extremes.

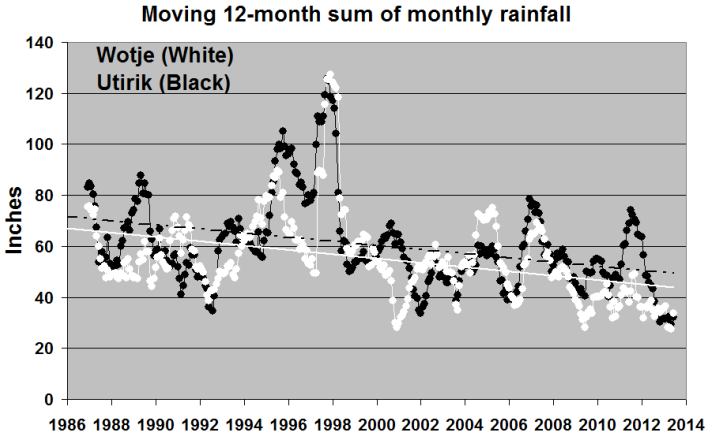


Figure 1. A nearly 30-year time series of rainfall for the atolls Wotje and Utirik in the Republic of the Marshall Islands. This record was developed to help inform the relief efforts to these atolls after their severe drought in the spring of 2013. The project PI helped to establish that the spring of 2013 was one of the driest time periods of record for these atolls

Another example of the collaborative work of the project PI with Chip Guard was the addition of Typhoon Lupit's rainfall to the Ulithi Atoll daily rainfall time series (Fig.2) The data for the whole week following Lupit is missing in the official data from NCDC. The typhoon rainfall was obtained directly by Mr, Guard from personal communication with the cooperative observer and is included in an after-action report on the effects of Typhoon Lupit on the atoll. This data point (missing in the official NCDC record) represents the extreme 24-hour rainfall in the historical record at this site. The Ulithi case is important because it shows how evaluations of return periods of rainfall extremes can be impacted by missing data. It is also important to other USGS research (such as the ongoing SERDP project) in which the water resources of the US-API are being evaluated for impacts of climate change. It is very important to get the historical record correct!

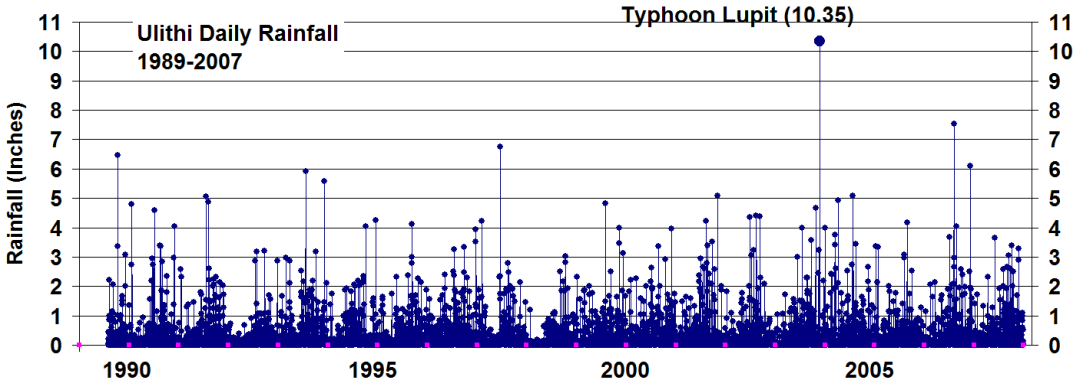


Figure 2. Time series of Ulithi Atoll daily rainfall with the Typhoon Lupit rainfall included. Note that the Lupit rainfall is the highest daily rainfall value in the time series, but this is not included in the official NCDC record.

Problems in the climate records of the US-API, like the two illustrated above, exist at most locations. Editing station records is a long, arduous and ongoing effort of the project PI in collaboration with Mr. Guard. It is not complete, and the ultimate step is to place our edits into the official records of the NCDC. Through Mr. Guard, there are channels for this to happen.

With a special grant from UOG Sea Grant (Dr. Laura Biggs, PI), the project PI was able to compile climatic data in the US-API from the Japanese period of administration from 1915 through 1937. An example is shown (Fig. 3 and 4) for the monthly rainfall on Palau and at Majuro during both the Japanese and American periods of administration (WWII years missing).

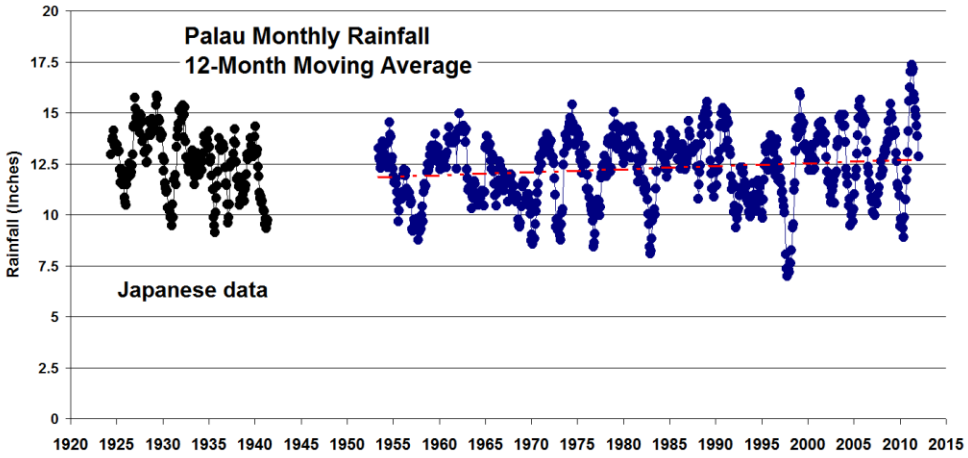


Figure 3. Time series of monthly rainfall at Palau for the period 1922-present. The Japanese data provides a crucial anchor to illustrate and investigate long-term trends at Palau and throughout the US-API.

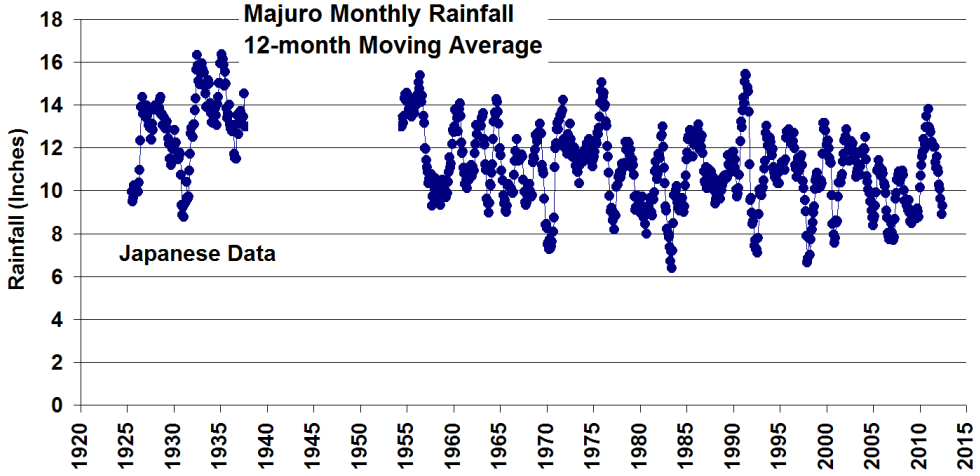


Figure 4. Time series of monthly rainfall at Majuro for the period 1922-present. The Japanese data provides a crucial anchor to illustrate and investigate long-term trends at Majuro and throughout the US-API.

One of the crucial findings of the project PI, is that there is a statistically significant drying trend at all the western Pacific US-API from Pohnpei and eastward to include Kosrae and all of the atolls of the RMI. A similar long-term drying is noted by other authors for the state of Hawaii. In western Micronesia (e.g., at Palau) there is a long-term trend for increasing rainfall over the U.S. period of administration, but this is not statistically significant, and even less so with the Japanese data included.

A major ongoing thrust of the efforts of the project PI is to establish benchmark rainfall amounts that correlate with impacts such as insufficient drinking water, enhanced risk of wild-fire, and other affects of drought. Mr. Richard Heim of the National Climatic Data Center has undertaken the task of including the US-API into the U.S. National Drought Monitor. This is important in that it is a U.S. government statutory requirement that USDA drought assistance must be preceded by mention in the Drought Monitor. I have worked with Mr. Heim, Mr. Chip Guard and others to help establish the Pacific Island benchmarks for the familiar D0 through D4 drought categories seen on the drought monitor (Fig. 5).

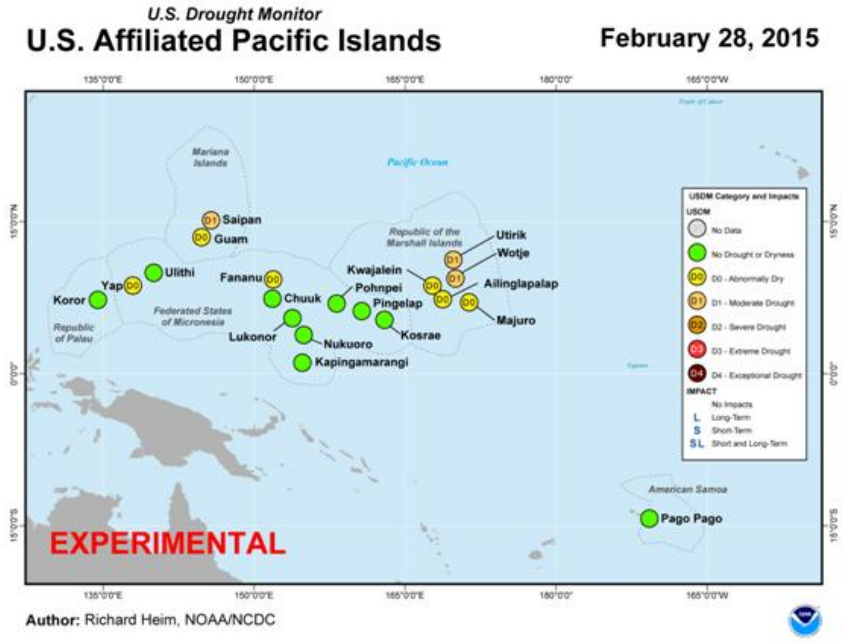


Figure 5. Experimental drought map for the US-API to be included in the U.S. Drought Monitor

Eventually this effort will lead to the incorporation of the US-API into the official U.S. Drought Monitor. The project PI was deeply involved in setting the benchmarks for the categories of drought in the US-API. This I consider to be my crowning achievement in the advancement of the goals of this project.

Information Transfer Program Introduction

WERI's research activities focus predominantly on local water resources problems and issues identified largely through discussions with regional stakeholders at our annual advisory council meetings. Disseminating the results of these investigations to appropriate governmental agencies, environmental managers, policy makers and other local decision makers in the water resources business, has the highest priority and is accomplished in various ways. Institutional technical reports remain a strong vehicle for transmitting such information to our target audiences, many of whom are remotely situated and do not have access to the scientific literature, or require a greater degree of detail than is normally permissible in a standard journal publication. WERI faculty have also become increasingly more interactive with audiences overseas in recent years by sharing their research findings at professional meetings, conferences and workshops at the national and international level. Our recently improved website is gaining increased popularity among professional circles, both at home and abroad, and is now accessible to the great majority of our stakeholders throughout the region. Our annual Advisory Council meetings in Guam, the CNMI and the FSM are highly effective information transfer mechanisms, bringing together people who typically have little to no contact with one another during the rest of the year. These meetings serve as a valuable forum of information exchange and discussion on common issues, problems and needs in the water resources arena. We remain strong in our commitment to teaching and training the up-and-coming water resources professionals of tomorrow, in addition to conducting workshops, courses and seminars for those currently employed in this area. Educating the students and teachers on the importance of protecting and preserving our fresh water resources remains one of the institute's high priority areas. WERI faculty also continue to be major and effective participants in water related law and policy making on Guam by serving as committee members and chairs on numerous governmental boards and by giving testimony at legislative oversight hearings.

Expanding Guam Water Kids with Five Modules to Prepare High School Students for Service-Learning Opportunities Beneficial to Freshwater Resources

Basic Information

Title:	Expanding Guam Water Kids with Five Modules to Prepare High School Students for Service-Learning Opportunities Beneficial to Freshwater Resources
Project Number:	2014GU269B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Conservation
Descriptors:	None
Principal Investigators:	Arretta Ann Card

Publication

1. Ann, Card, 2014, Guam Water Kids & Learning about Guam s Fresh Water: A high school service learning project for Guam Public Schools, www.guamwaterkids.com , WERI Technical Report, University of Guam, Mangilao, Guam, 150 pages.

PROJECT SYNOPSIS REPORT

Project Title: Expanding 'Guam Water Kids' with Five Modules to Prepare High School Students for Service-Learning Opportunities Beneficial to Freshwater Resources

Problem and Research Objectives

It was determined that the use of "Guam Water Kids," localized teaching materials about the importance of protecting and preserving fresh water resources could be extended for instructional use with high schools students by developing materials specifically designed for use in the service-learning program of the Guam Department of Education (GDOE).
Some 9,000 high school students were required participate in service-learning for the first time in the 2014-2015 school year. The superintendent's service-learning representative, Dr. Eloise Sanchez, had shared an urgent need for materials to assist teachers in preparing their students to participate in community service and approved participation of "Guam Water Kids" as a community partner. The objectives of this proposal were to fill this need by:

- Providing Service-Learning Modules — Five appropriate learning modules about fresh water resources for use in the service-learning program to prepare teachers and their students to (1) participate in service projects that are beneficial to fresh water resources and to (2) make "Guam Water Kids" presentations to middle school students, youth groups and other community organizations.

- Aligning to Common Core State Standards — Follow the STEM (Science, Technology, Engineering and Math) format and modules to the nationwide Common Core State Standards. Existing "Guam Water Kids" Lesson Plans to be updated from old standards in use to these newly adopted national standards.

- Supporting with "Guam Water Kids" Website — Expand the teacher support section of www.guamwaterkids.com to introduce the new service-learning modules and deliver corresponding content/resource. Perform an update to the existing self-paced slide shows for use with tablets and smart boards to increase technology in learning opportunities.

- Survey participating educators to evaluate the use and effectiveness of "Guam Water Kids" service-learning modules in face-to-face interviews preserving appropriate contact information and notes.

This proposal addressed WERI's stated critical water resources need targeted to educational training and outreach programs about the importance of protecting and preserving watersheds and water resources. It also addressed a need vocalized by the Advisory Council that the "Guam Water Kids" should be institutionalized into the Guam Department of Education (GDOE) public school system.

Methodology

The materials developed were designed to fulfill the needs of the teachers and students participating in the GDOE service-learning program by creating a self-contained, activity-based resource. The modules include a complete set of differentiated learning tasks, activities, defined vocabulary, worksheets, assessments and performance task rubrics for each module. An important component was inclusion of basic background information for information on each topic. The following tasks were completed:

A. The five service-learning modules are classroom-ready products that teachers can use in a series or as independent lessons. Each module contains material for five class sessions. The modules follow the outline of the "Guam Water Kids" presentation with content serving as both a review and an orientation for high school students and as a tool to be used with volunteer activities with emphasis on using the original Guam Water Kids presentation to share the importance of protecting and conserving Guam's fresh water resources. Modules follow the GDOE's adopted service-learning lesson format (investigate, prepare, act, reflect, demonstrate). Consistent with "Guam Water Kids" materials, the information and activities are localized to Guam.

   Modules topics:

   - Define fresh water and fresh water resources on Guam, the value of fresh water, threats and solutions for sustainability, personal responsibility and taking action.
   - Overview of how we get fresh water including water cycle, where fresh water is stored on Guam, and the fresh water in the "ridge to reef" connection.
   - How watersheds and aquifers work and related threats to sustainability.
   - Interconnection of fresh water in ecosystems on Guam, impact of human activities.
   - What individuals can do through service-learning and throughout life, volunteering, connecting with community efforts, citizen leadership, formal education and careers.

Each module contains a teacher's step-by-step guide, lesson, activities focused on take-action learning, opportunity for reflection and additional resources.

B. Alignment to Common Core State Standards is key for Guam teachers. Lessons in the five modules for high school service-learning follow the STEM (Science, Technology, Engineering, Mathematics) format. In addition, the two original "Guam Water Kids" lessons for middle school were updated to follow these recently-adopted standards.
C. Support from the "Guam Water Kids" website includes the addition of the high school service-learning in a downloadable format. The materials on the website are flagged with references to Common Core State Standards.
D. In addition to an onsite survey, teacher's experiences were collected in orientation settings in small group and individual settings. Evaluating teacher feedback through the survey will be ongoing which will help us learn more about the serving educators.

The five service-learning modules were developed by Ann Card and Jennifer Berry. Ann Card is a former UOG faculty member who has developed university courses, edited online professional development courses for classroom teachers, and has written, edited and produced public education projects in the fields of environmental education, cultural heritage, history and health on Guam. Jennifer Berry holds a master's degree in education and has taught in Guam public schools for more than 20 years and is a Certified Resource Teachers and a youth volunteer in several organizations including Girl Scouts.

Principal Findings and Significance

When the materials were completed, Ann Card and Jennifer Berry met with administrators, science teachers and other educators for face-to-face briefings about the materials during professional development workshops in the schools, professional meetings and individual contact. Several suggestions and needs for clarification were offered and subsequently incorporated. The teachers' responses were very favorable and several made specific plans to incorporate the program next fall.

The finalized materials were presented to the superintendent's service-learning representative, Dr. Eloise Sanchez, who approved participation of "Guam Water Kids" as a community partner in the Guam DOE Service-Learning project. All six Guam public high schools received the materials in hard copy in a 230-page document and on DVD and for download online at guamwaterkids.com/service.html. In addition the Home School Association and several other interested educators received copies. At the beginning of the fall semester, high school teachers will be reminded of the availability of these materials through GDOE's email announcement. Additional copies and orientation sessions upon request. As per the request of teachers, the materials will be offered on a USB flash drive at that time.

As a result of this project, materials encouraging integration of the importance fresh water to Guam are available to high school teachers an incorporated through the service- learning program. The viability of the "Guam Water Kids" program (originally developed for middle school students) has been expanded to the high school level. The underlying theme of the Guam Water Kids program—the development of a sense of stewardship and an understanding that we are all responsible to protect fresh water—may contribute to an educated citizen base willing to help make fresh water sustainable on Guam.

An excerpt of the final project report with teacher comments and photos follows.

excerpted from the Final Report—104-B Grant:
Expanding 'Guam Water Kids' / High School Service Learning Modules

Surveying Participating Educators

All six public high schools on Guam have received information about the availability of the "Guam Water Kids" and Learning about Fresh Water High School Service Learning program. High School principals have received information and a lead contact has also been contacted and briefed.

A total of thirty-one high school teachers have attended professional development orientation sessions at Southern, Okkodo, Simon Sanchez, George Washington and John F. Kennedy High Schools. In addition, eleven teachers have received information and signed the contact sheet at the January IRA professional educators' meeting.

The professional development group orientations conducted on site in group sessions of about 45 minutes organized by the schools. The teachers attending have been predominantly science teachers. Teachers received copies of the manual's introduction section regarding purpose and organization. The complete full document was passed around during the session and a master copy of the program was presented to each school at the close of the session. Excerpts from the "Guam Water Kids" slide were shown and Module 1 was presented in detail as an example. In addition, a class of 25 high school students at Southern High School participated in an introductory session to informally gauge student receptivity.

Southern High School students, Dr. Mariam Piana, Jennifer Berry, Ann Card.

Teacher Comments:
Following are comments offered in discussions after the 45-minute orientation session grouped around four opened-ended questions asked.

Appropriate to Instructional Content?

- "This follows our curriculum and will fit in perfectly."
- "My students need to see Guam images and understand how important our fresh water is"
- "I teach special needs. A group of my students is studying marine biology by regularly observing turbidity at Ypao Beach. They are so motivated. I can use this program to add fresh water to our studies."
- "I can start my students on this when we study fresh water. They will get a review and be motivated to learn."

Review of Materials Provided?

- "I see everything we need to start using this to get our service learning going."
- "Like the localized science."
- "I'm so glad you have assessments. This is really a key."
- "You've done our homework for us!"
- "Really, this is very complete with the activities all lined out."
- "Useful."
- "Will share it with other teachers."

Might You Use for Service-Learning?

- "Yes, we're looking for service learning materials. This is a gift!"
- "We have limited funds for busing students to field trips but we have a middle school just next door and where our students could make presentations."
- "I am going to use this with my 4th period group starting right after spring break."
- "I won't use this in service learning—I'm going to incorporate it into my course instruction every year!"
- "My seniors have completed their service learning for this year, but I can use it in the fall."
- "Glad it is available."

Your Additional Needs?

- Can we get additional copies for our school?
- "I'd like to have a MSWord file (instead of only a .pdf file) in case I want to adapt."
- No DVD player on my laptop, can we copy it from a flash drive?
- "We are looking for credit hours in continuing education."
- "I want to join your team!"

One-Day Field Course for Water Resource Professionals and Island Educators, with Educational Webpage on the Northern Guam Lens Aquifer

Basic Information

Title:	One-Day Field Course for Water Resource Professionals and Island Educators, with Educational Webpage on the Northern Guam Lens Aquifer
Project Number:	2014GU270B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Ground-water Flow and Transport
Focus Category:	Education, Groundwater, None
Descriptors:	None
Principal Investigators:	John Jenson

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: One-Day Field Course for Water Resource Professionals and Island Educators, with Educational Webpage on the Northern Guam Lens Aquifer

Problem and Research Objectives

The planned military buildup and associated economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam's groundwater resources. To arrive at appropriate policy, regulations, and management practices and obtain public support it is essential that policy-makers, water resource professionals, and island educators be equipped with an accurate and up-to-date understanding of the essential characteristics of the island's aquifer and the factors that must be considered to frame and implement sustainable management practices.
A universal challenge, however, is that policy-makers, community leaders and other professional people have extremely limited time to engage in instructional opportunities.

Specific critical needs for *Education and Professional Training* identified by the 2014 *WERI Advisory Council*, by the instructional program, include the following under Section IV, EDUCATION AND PROFESSIONAL TRAINING:

- Item1. Executive training on water resources issues for Legislators and Gov. of Guam senior management officials, including CCU
- Item 2. Develop community water resources awareness and education projects
- Item 3. Develop K-12 education projects on island water resources and pollution prevention.
- Item 8. Develop public education programs on the costs of water quality
- Item 11. Develop teacher training courses in water resources related subjects
- Item 12. Develop general public training in water resources issues especially in getting technical matters into a language the general public can understand
- Item 13. Develop educational training and outreach programs within the community about the importance of protecting and preserving our watersheds and water resources.
- Item 14. Design research data driven training courses for Guam Waterworks Authority to facilitate improved management practices of the island's water resource

Methodology

We developed and delivered a field course for water resource professionals and educators consisting of (1) a single day of intensive personal instruction delivered in the field, with (2) a binder of materials and a supporting webpage containing instructional materials and links to external resources. Dr. Jenson (field instructor) developed the course content and field trip itinerary. Dr. Taboroši (course material editor) designed and developed a 36-page field guild supported by web-based resources. On the days of field trips, Dr. Jenson rides with the participants in a tour bus, delivering instruction at not only the four selected stops, but during the time between stops.

During the field trip, participants are shown the basement rock that underlies and forms the hydrologic boundary of the aquifer, a large quarry in which the aquifer rock is well exposed, a sinkhole in which rapid entry of water can be observed, and the summit of the highest hill above the aquifer from which the entire catchment can be observed. Between stops, Dr. Jenson delivers instruction from the field guide concerning the basic aspects of aquifer geology, hydrology, and management. The course has been well received and continues to prompt requests from local agencies, engineering professionals, and educators for future offerings.

Principal Findings and Significance

This course provides island leaders, water professionals, and island educators with

(1) An introduction, in the field, to the Northern Guam Lens Aquifer, including the rock units and watersheds that comprise the aquifer
(2) An understanding of how and where the aquifer captures, stores, releases, and discharges potable water
(3) An understanding of the considerations that govern successful exploration, development, and protection of groundwater resources
(4) An introduction to the hydrogeologic conditions and economic factors that constrain resource development and determine appropriate criteria for sustainable management

The itinerary for the trip is shown below:

0830-0900: Participants board the bus

0930-1000, Stop #1: The Floor of the Aquifer – the Alutom Formation

- Aquifer basement rock, Mount Alutom. Here we will see examples of the impermeable volcanic rock that underlies the entire Northern Guam Lens Aquifer. This stop also provides an impressive view of the aquifer catchment from the south.

1045-1130, Stop #2: The Core of the Aquifer – the Barrigada Limestone

- Aquifer core rock, DPW Quarry, Dededo. Active quarrying of the limestone here provides some of the island's best exposures of the rock that comprises the core of the aquifer, along with examples of the kinds of porosity that constitute the internal plumbing of the aquifer.

1145-1230, Stop #3: Surface Plumbing of the Aquifer – Sinkholes, Shafts & Caves

- Surface water and sinkhole, Mataguac Hill Peace Memorial Park. In addition to its significance as a World War II historical site, the Peace Memorial Park provides close-up views of outstanding examples of the features by which rapid surface runoff enters the aquifer.

1245-1315, Stop #4: The Aquifer Catchment – Surface of the Northern Guam Plateau

- Vista of Entire Aquifer, Summit of Mount Santa Rosa. This final stop provides a spectacular "big picture" view of the entire aquifer surface, including each of its several basins. Also visible from this vantage point is the land use across the aquifer.

1345-1400: Bus returns to starting point

Develop community based watershed management programs to improve water quality of community water systems in Pohnpei, Federated States of Micronesia-FSM

Basic Information

Title:	Develop community based watershed management programs to improve water quality of community water systems in Pohnpei, Federated States of Micronesia-FSM
Project Number:	2014GU279B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Management and Planning, Water Quality, Education
Descriptors:	None
Principal Investigators:	Joseph Eugene, Francisca Sohl Obispo

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Develop community based watershed management programs to improve water quality of community water systems in Pohnpei, Federated States of Micronesia-FSM.

Problem and Research Objectives

Water is essential and part of our daily life. The steep, tropical watersheds of Pohnpei, Federated States of Micronesia can provide ample water for distribution and usage to everyone, as long as upstream forests are properly managed. Water shortages are often caused by deforestation and water quality is often compromised by harmful farming techniques. Example of harmful or unsafe farming techniques is raising livestock especially pigs near the river bank, washing the pig waste into the rivers and causing bacteria or polluting the waters around Pohnpei. Water quality is one of the main issues around the island and it's due of rapid growth of population, people build their houses close to the rivers and do their farming right on the river banks.

The goal of this project was to aid communities adjacent to the Watershed Forest Reserve (WFR) areas to implement their Conservation Action Plan (CAP), develop adaptive management plans, improve Watershed management through public and private partnerships, develop sustainable alternative sources of income and finally to promote conservation law enforcement. This project would contribute to the enhanced integrated management and sustainability of Pohnpei's watershed steering committee network. In addition, this project would also improve the practice of managing the watershed to improve our waters and conservation throughout Micronesia. The objectives of the project were:

- To develop community-based sustainable watershed management plan using The Nature Conservancy's (TNC) Conservation Action Plan (CAP) tools
- Rehabilitate, monitor, enforce and protect watershed sites through existing community-based Forest Ranger program;
- Implement biophysical monitoring and keep records of monitoring data to help steer management decisions on improving watershed and water quality in Pohnpei

Methodology

Direct coordination and involvement of all the watershed Community Conservation Officers (CC0's) network members and/or stakeholders is key towards the protection and rehabilitation of Pohnpei's natural forest and resources. There needs to be support, understanding, and involvement of all the community members and stakeholders. Enforcement, rehabilitation and monitoring of Pohnpei's Watershed Forest Reserve will be required to be carried out and engaged in a timely and lawfully efficient manner. In order to be an effective and sustainable WFR network, community members within a WFR designated site must be well informed and adopt this effort to enforce, rehabilitate and monitor Pohnpei's WFR.

Principal Findings and Significance

A. Pohnpei Watershed Forest Reserve Monitor result of 2014

The Conservation Society of Pohnpei (CSP) and the Pohnpei State Division of Forestry in collaboration with the Pohnpei Forest Rangers have conducted and completed 2014 forest monitoring. They have conducted their first monitoring on April 2014, second forest monitoring on June 2014, third quarter on September 2014 and fourth quarter on December 2014. Their monitoring result shows that there were no clearings found in the Watershed Forest Reserve WFR of Madolenihmw and U Municipalities. The identified sites monitored in Madolenihmw were Pihs, Nihpit, Sapwalap, Nan Kehlik and Dolen Lepen. The monitoring activity in U Municipality covered the areas of Nan Welin Rohi, Tipwen, Pahn Takai and reported no new clearings. CSP and Forest rangers are still continuing with the forest monitoring to keep collecting data and making sure that people are not clearing the forest.

B. Community Conservation Officers Cross site visit 2014

On November 14-15, the Locally Managed Marine Areas (LMMA) and Forest Rangers network of Pohnpei also known as Pohnpei Marine Protected Areas Network conducted its annual learning exchange workshop. Over the past 11 years, the LMMA sites of Pohnpei unite for an annual learning exchange through what is called the Cross-site Visit. This year marked a milestone for this unique network as it celebrated its 11th anniversary. Community members from the locally managed Marine Protected Areas (MPA) and Forest Rangers of Pohnpei gathered at the community center of Nan Wap in the village of Lukop for two days to share the lessons learned from their respective locally managed sites. Community conservation officers from each of the LMMA sites and Watershed Forest Reserved are shared what they accomplished in their 2014 action plans. Representatives from each LMMA site and forest reserved also worked on action plans for the upcoming year. With the action plans created at this year's cross-site visit, the Conservation Society of Pohnpei (CSP) will continue to work closely with these communities by assisting in the capacity building of our community conservation officers. Over the years, CSP have built strong partnership with communities throughout Pohnpei who share the same goals and objectives in resource management.

C. Forest Ranger's Workshop

January 21, 2015, CSP with the partnership of Pohnpei Forestry Office were able to organize and conducted a Watershed workshop. Participants include various key players from office of Fish and Wild Life, Environmental Protection Agency, Watershed Steering Committee, Forest Rangers and communities. Purpose of the workshop is to gather all the key players to find ways to work together as a team to help maintain our watersheds to protect and improve our water quality.

There were three presentations done by our partners, Forestry office, Division of Fish & Wild Life and Environmental Protection Agency. These presentations help lead us in our discussions to improve and maintain our watershed to protect our waters. After all the presentation we did group work to set our priorities and ways we can work together to help maintain our watershed and protect our waters. The result of group work we have identified three main things we need to work on and they are the following:

- We have identified that there's need to share the result of every work and research that each partner have done on the island back to the communities. Like water test result, regulations from EPA and even the forest monitoring results.

- We need to do community awareness program with the communities and at the same time to develop their own action plans, ways they can improve and maintain their own water, rivers and watershed.

- All partners need to do a follow up visit with these communities along with Municipal government. And we have identified that the Watershed Steering Committee will take the lead on the community awareness programs or meetings with the help of CSP.

At the end of the workshop all agreed to work together as a team to help protect our watershed and our waters by communicating back to our neighbors on what's happening now and ways we all can protect and improve our waters.

Sustainable Conjunctive use of Groundwater and Rain Catchment Water under Variable Climatic Scenarios for Atoll Island Communities

Basic Information

Title:	Sustainable Conjunctive use of Groundwater and Rain Catchment Water under Variable Climatic Scenarios for Atoll Island Communities
Project Number:	2014GU280B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	None
Principal Investigators:	John Jenson

Publications

1. Wallace, Corey D., 2015, Atoll island freshwater resources: modeling, analysis, and optimization, MS Dissertation, Department of Civil and Environmental Engineering, College of Engineering, Colorado State University, Fort Collins, Colorado, 222 pages.
2. Wallace, Corey D. and Ryan T. Bailey, in prep, 2015, Atoll island freshwater resources: modeling, analysis, and optimization, MS Dissertation, Water and Environmental Research Institute of the Western Pacific, Technical Report, University of Guam, Mangilao, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Sustainable Conjunctive use of Groundwater and Rain Catchment Water under Variable Climatic Scenarios for Atoll Island Communities

Problem and Research Objectives

Water shortages are a persistent concern on atoll islands. Under normal conditions, demand is met by rooftop rain catchment, but prolonged droughts can exhaust storage, leaving residents dependent on groundwater or imported water. The objectives of this project were to (1) use modeling to assess daily freshwater supply for specific islands in the FSM and to (2) provide training to FSM water and environmental officials.

Methodology

This study used spreadsheet tools to assess fresh groundwater resources and stored rainwater catchment volumes during variable climatic scenarios. The spreadsheet tools for freshwater lens thickness and lens volume calculations are based on results from a comprehensive suite of numerical modeling simulations. Freshwater lens thickness and volumes were estimated according to probable scenarios of sea-level rise, with a given rate of sea-level rise resulting in estimates of shoreline recession for varying degrees of beach slope. The stored rainwater volumes are estimated using a daily water balance model that accounts for roof catchment area, transfer efficiency, storage tank size, and household demand. For both groundwater and rainwater calculations, rainfall patterns and scenarios were based on results from General Circulation Models (GCMs) participating in the Coupled Model Intercomparison Project 5 (CMIP5). Only GCMs that tested well against historical rainfall data from the FSM regions (western, eastern) were used. Using the suite of GCM results, rates of sea-level rise, and degree of beach slope, a range of lens thickness values were computed for each atoll island in the FSM for the years 2030 and 2050. Using the results of the rainwater catchment water balance tool, design curves were constructed that provide combinations of roof catchment area and storage tank volume that yield certain levels of reliability (e.g., 95% reliability, meaning that sufficient water is stored to meet demand for 95% of the time). Results of the study were used to provide training to FSM water and environmental officials during the FSM advisory meeting on Pohnpei in October, 2014. Training was provided on the use of the spreadsheet tools for specific island settings.

Principal Findings and Significance

Results of using the spreadsheet tool can help manage groundwater and rainwater resources for atoll island communities. Some of the methods developed in this study are novel and can be applied to many geographic and island settings worldwide. For example, the methodology for developing rainwater catchment system design curves using GCM output can be used in any geographic region. The training from the workshop will enable FSM water resources managers and planners to make more reliable policies and plans to support or build sustainable communities with good quality of life on the atoll islands of the FSM. Improving water resources availability and sustainability on small island communities will promote economic and social stability, as well as preserving the preferred way of life for many current and future residents of the FSM.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2014GU281B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NA
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	None
Principal Investigators:	Shahram Khosrowpanah

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

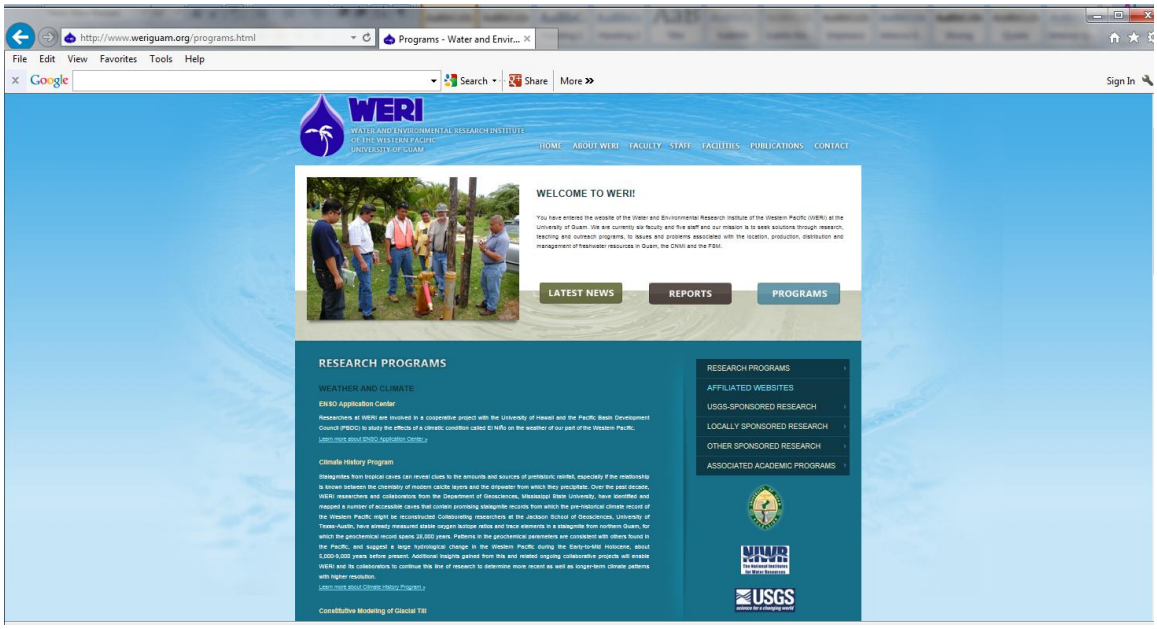
WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such as brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied geographically and by education level. It is important that WERI make this information available in a very widely distributed form.

The WERI web-site is the Institute's primary Information Transfer/Dissemination mechanism. The home page, shown below, is located at http://www.weriguam.org/. It features informational links to WERI faculty, staff and Institutional facilities, our current research, education and training activities, primary sponsors and most recent publications. The user friendly format is intended to increase visibility of the Institute's research programs and associated projects particularly for our stakeholders in remote locations where state-of-the-art internet services and computer technology are often lacking.

WERI Web-site Home Page

This project also funded the design, layout and printing of five (5) major technical completion reports resulting from USGS funded research projects. Fifty (50) hard copies of each report were printed. All WERI technical completion reports are available in downloadable PDF format on the WERI web-site at http://www.weriguam.org/reports/list.

The technical completion report library was updated with several new additions. The improved database search engine process for accessing these reports on line utilizes a composite 'Abstract' database for key word searches. Searches based on 'Author' now search all authors in the author string not just the lead author as before. Upon selection of a particular report, site users are presented with the complete abstract, which may be viewed prior to downloading the main report. An example is shown below.

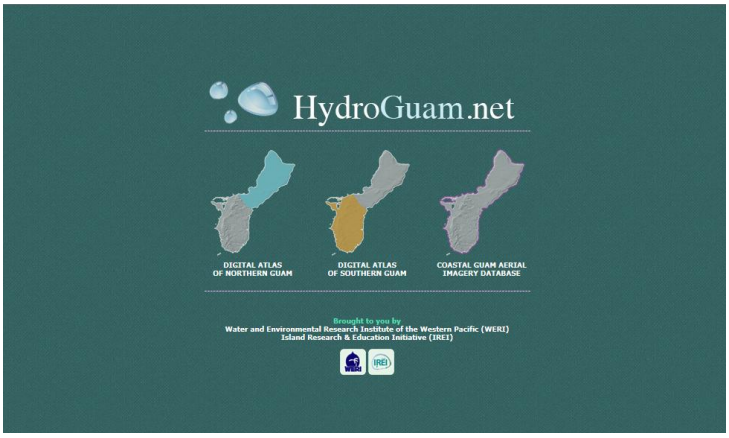


WERI Reports Page

Because of Guam's remote location, and the escalating costs of air travel, it is difficult and costly for researchers to present their findings at technical conferences and symposiums in other parts of the Globe. A portion of the current Information Transfer Project was earmarked for off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past USGS 104-B projects.

In 2005, WERI revealed a unique digital data repository entitled "Natural Resources Atlas of Southern Guam". That resource was inspired by the need for up-to-date baseline information required for sustainable development and other decision making. Its mission was to provide a comprehensive picture of the natural resources found within the fourteen southern Guam watersheds and make that information instantly available to users. The atlas proved to be a highly effective data dissemination hub, as well as a much-used awareness and educational tool. At its core lay a wide range of Geographical Information System (GIS) data for southern Guam, providing valuable support for resource management and research, including hydrologic modeling, pollution prevention, soil conservation, and coastal zone management. The tool

became very popular in Guam thanks to its simple and user-friendly data dissemination approach: all geospatial data are stored and formatted in such a way that the full content is freely accessible on the Internet via *www.hydroguam.net* address. The web interface also offers a range of additional textual, graphical, statistical, and geographic information to any interested user. Within a relatively short time, the "Natural Resources Atlas of Southern Guam" became so successful that in 2012 it inspired a "sister" project, which was to develop a comparable resource for Northern Guam. That work was completed in late 2013. In 2014, the southern Guam was updated to reflect the new additional information. The new product is entitled "Digital Atlas of Northern Guam" and encompasses many of the strengths of the previously created "Natural Resources Atlas of Southern Guam" with a series of significant improvements. The "Digital Atlas of Northern Guam" is freely accessible on the Internet via: *www.hydroguam.net* address.



USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

As was reported last year FY 2013, the University of Guam undertook a thoroughgoing assessment of its programs, in preparation for a major re-prioritization and realignment of resources between programs, ranging from elimination of the weakest to heavy reallocation and investment in the strongest programs with the greatest potential. Initiated two years ago by the university president, the final plan was approved by the university's Board of Regents on May 2014. From among the 60 academic and research program units that were evaluated in terms of demand and quality, WERI was one of nine selected among 60 academic and research program units as the university's flagship programs. This will give the institute heavy additional investment and expansion over the next several years. In early 2015, the institute hired a new faculty in the area of groundwater modeling. This will increase our research, training, and informational activities in a high priority area.

According to the provisions of section 104 of the Water Resources Research Act of 1984, as amended, during FY 2014, WERI was evaluated for their activities and eligibility for continued support under the Act. The result:

"We are pleased to inform you that the Water and Environmental Research Institute of the Western Pacific is performing at an outstanding level and is eligible for continued support under the Act. This decision is based on a recent report and recommendation by a panel convened to evaluate the activities of the 54 institutes or centers authorized by the Act during the period 2008 through 2010."

Comment highlights were:

The Institute continues to show significant research accomplishments and demonstrates impacts on public policy and water management throughout the region. The panel commends the separate advisory councils that exist for Guam, the Commonwealth of the Northern Marianas Islands (CNMI), and the Federated States of Micronesia (FSM) for its continued efforts to hold annually regional council meetings. The Institute is to be commended for remaining committed to focusing in a programmatically separate way on the problems of Guam , FSM, and CNMI. This is very important given that the water problems differ significantly between the areas. The Institute 's success is partly due to the support provided by the University of Guam , the Guam Hydrological Survey, and Guam Water Comprehensive Monitoring g Program , and the Institute 's leveraging capacity.

Publications from Prior Years

1. 2013GU250B ("Development of Environmentally Sustainable methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island") - Other Publications - : Rouse, Joseph D., 2014, Sustainability of Effective Wastewater Treatment Practices on Yap Island, Regional Island Sustainability Conference, Center for Island Sustainability, Univ. of Guam; Hyatt Regency, Tumon, Guam; April 15-16, 2014.
2. 2013GU250B ("Development of Environmentally Sustainable methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island") - Conference Proceedings - Rouse, Joseph D., 2014, Development of Environmentally Sustainable Methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island. The 4th World Sustainability Forum, 1-30 November 2014. OPEN ACCESS : http://www.sciforum.net/conference/wsf-4
3. 2013GU250B ("Development of Environmentally Sustainable methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island") - Water Resources Research Institute Reports - Rouse, Joseph D., 2015, Development of Environmentally Sustainable Methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island, WERI Technical Report No. 153, Water and Environmental Research Institute of the Western Pacific, Univ. of Guam, Mangilao, Guam, 21 pages.
4. 2009GU162B ("Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon") - Articles in Refereed Scientific Journals - Denton, Gary R.W., Carmen A. Emborski, Nathan C. Habana, and John A. Starmer, 2014. Impact of Urban Runoff, Inappropriate Waste Disposal Practices and World War II on the Heavy Metal Status of Sediments in the Southern Half of Saipan Lagoon, Saipan, CNMI. Marine Pollution Bulletin, 81: 276-281.
5. 2011GU200B ("Environmental Impact of FUDS and Brownfields Sites in Watersheds on the Eastern Side of Saipan. Phase 1: Contaminant Analysis of Soil and Sediments") - Other Publications - Denton, Gary R.W, and John A. Starmer, 2014, Heavy Metals in WWII Dumpsites along Saipan s Eastern Seaboard. Part 1: Impact on Soils and Sediments (Abstract) Annual General Meeting, Asia Pacific Academy of Science and Environmental Management, American Memorial Park Auditorium, Saipan, November 18-20, 2014.
6. 2012GU222B ("Environmental Impact of FUDS and Brownfields Sites in Watersheds on the Eastern Side of Saipan: Phase 2. Impact on Aquatic Resources") - Other Publications - Denton, Gary R.W, and John A. Starmer, 2014, Heavy Metals in WWII Dumpsites along Saipan s Eastern Seaboard. Part 2: Impact on Aquatic Organisms (Abstract) Annual General Meeting, Asia Pacific Academy of Science and Environmental Management, American Memorial Park Auditorium, Saipan, November 18-20, 2014.
7. 2013GU245B ("Heavy Metal Status of Nearshore Fisheries Impacted by Old Military Dumpsites on the Eastern Side of Saipan, CNMI") - Other Publications - Denton, Gary R.W, 2015, Manageability of Environmental Mercury Sources in Saipan (Abstract) Coral Reef Symposium, Hyatt Hotel, Tumon Guam, April 14, 2015.
8. 2013GU248B ("Land Cover Change Detection in Saipan") - Water Resources Research Institute Reports - Wen, Y. , Dereck. Chambers, 2014, Land cover change detection in Saipan, Technical Report 149, Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, 144 pages.
9. 2007GU94B ("Land Cover Accuracy Assessment for Southern Guam") - Other Publications - Wen, Y. , 2015, Land Cover Change in Guam , 36th College of Liberal Arts and Social Sciences Annual Research Conference, University of Guam, Mangilao, Guam, March 10, 2015.
10. 2009GU156B ("Impacts of Land Cover Change on Groundwater Quality in Guam") - Other Publications - Wen, Y., 2015, GIS-based Analysis of Groundwater Quality Data on Guam , Island Sustainability Conference, University of Guam, Hyatt Regency, Tumon, Guam, April 15 16, 2015.

11. 2012GU218B ("Spatial and Temporal Analyses of the Relationship Between Groundwater Salinity and Rainfall Amounts, Timing, and Intensity in the Northern Guam Lens Aquifer") - Water Resources Research Institute Reports - Vann, David T., Vivianna M. Bendixson, Douglas F. Roff, Christine A. Simard, Robert M. Schumann, Nathan C. Habana, and John W. Jenson, J.W, 2014, Topography of the Basement Rock beneath the Northern Guam Lens Aquifer and Its Implications for Groundwater Exploration and Development. WERI Technical Report No. 142. University of Guam, Mangilao, Guam, 71 pages.